

A P P L I C A T I O N

for

UNITED STATES LETTERS PATENT

on

SURFACE EXPRESSION LIBRARIES
OF RANDOMIZED PEPTIDES

by

WILLIAM D. HUSE

CERTIFICATE OF MAILING BY "EXPRESS MAIL"

"EXPRESS MAIL" MAILING LABEL NUMBER: EL6901555570S

DATE OF DEPOSIT: November 29, 2000

I HEREBY CERTIFY THAT THIS PAPER OR FEE IS BEING
DEPOSITED WITH THE UNITED STATES POSTAL SERVICE
"EXPRESS MAIL POST OFFICE TO ADDRESSEE" SERVICE
UNDER 37 CFR 1.10 ON THE DATE INDICATED ABOVE AND IS
ADDRESSED TO THE COMMISSIONER FOR PATENTS, ATTENTION
BOX PATENT APPLICATION, WASHINGTON, D.C. 20231.

Sheets of Drawings: Sixteen

Docket No.: P-IX 4526

Astrid R. Spain

Printed Name of Person Mailing Paper or Fee

Astrid R. Spain

Signature of Person Mailing Paper or Fee

Attorneys

CAMPBELL & FLORES LLP
4370 La Jolla Village Drive
7th Floor
San Diego, California 92122

SURFACE EXPRESSION LIBRARIES
OF RANDOMIZED PEPTIDES

This application is a continuation-in-part of U.S. Serial No. 07/590,664, filed on September 28, 1990.

5

BACKGROUND OF THE INVENTION

This invention relates generally to methods for synthesizing and expressing oligonucleotides and, more particularly, to methods for expressing oligonucleotides having random codon sequences.

10

Oligonucleotide synthesis proceeds via linear coupling of individual monomers in a stepwise reaction. The reactions are generally performed on a solid phase support by first coupling the 3' end of the first monomer to the support. The second monomer is added to the 5' end of the first monomer in a condensation reaction to yield a dinucleotide coupled to the solid support. At the end of each coupling reaction, the by-products and unreacted, free monomers are washed away so that the starting material for the next round of synthesis is the pure oligonucleotide attached to the support. In this reaction scheme, the stepwise addition of individual monomers to a single, growing end of a oligonucleotide ensures accurate synthesis of the desired sequence. Moreover, unwanted side reactions are eliminated, such as the condensation of two oligonucleotides, resulting in high product yields.

15

20

25

30

In some instances, it is desired that synthetic oligonucleotides have random nucleotide sequences. This result can be accomplished by adding equal proportions of all four nucleotides in the monomer coupling reactions, leading to the random incorporation of all nucleotides and yielding a population of oligonucleotides with random

sequences. Since all possible combinations of nucleotide sequences are represented within the population, all possible codon triplets will also be represented. If the objective is ultimately to generate random peptide products, this approach has a severe limitation because the random codons synthesized will bias the amino acids incorporated during translation of the DNA by the cell into polypeptides.

The bias is due to the redundancy of the genetic code. There are four nucleotide monomers which leads to sixty-four possible triplet codons. With only twenty amino acids to specify, many of the amino acids are encoded by multiple codons. Therefore, a population of oligonucleotides synthesized by sequential addition of monomers from a random population will not encode peptides whose amino acid sequence represents all possible combinations of the twenty different amino acids in equal proportions. That is, the frequency of amino acids incorporated into polypeptides will be biased toward those amino acids which are specified by multiple codons.

To alleviate amino acid bias due to the redundancy of the genetic code, the oligonucleotides can be synthesized from nucleotide triplets. Here, a triplet coding for each of the twenty amino acids is synthesized from individual monomers. Once synthesized, the triplets are used in the coupling reactions instead of individual monomers. By mixing equal proportions of the triplets, synthesis of oligonucleotides with random codons can be accomplished. However, the cost of synthesis from such triplets far exceeds that of synthesis from individual monomers because triplets are not commercially available.

Amino acid bias can be reduced, however, by synthesizing the degenerate codon sequence NNK where N is a mixture of all four nucleotides and K is a mixture of guanine and thymine nucleotides. Each position within an oligonucleotide having this codon sequence will contain a total of 32 codons (12 encoding amino acids being represented once, 5 represented twice, 3 represented three times and one codon being a stop codon). Oligonucleotides expressed with such degenerate codon sequences will produce peptide products whose sequences are biased toward those amino acids being represented more than once. Thus, populations of peptides whose sequences are completely random cannot be obtained from oligonucleotides synthesized from degenerate sequences.

There thus exists a need for a method to express oligonucleotides having a fully random or desirably biased sequence which alleviates genetic redundancy. The present invention satisfies these needs and provides additional advantages as well.

SUMMARY OF THE INVENTION

The invention provides a plurality of procaryotic cells containing a diverse population of expressible oligonucleotides operationally linked to expression elements, the expressible oligonucleotides having a desirable bias of random codon sequences.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic drawing for synthesizing oligonucleotides from nucleotide monomers with random triplets at each position using twenty reaction vessels.

Figure 2 is a schematic drawing for synthesizing oligonucleotides from nucleotide monomers with random tuplets at each position using ten reaction vessels.

Figure 3 is a schematic diagram of the two vectors used for sublibrary and library production from precursor oligonucleotide portions. M13IX22 (Figure 3A) is the vector used to clone the anti-sense precursor portions (hatched box). The single-headed arrow represents the Lac p/o expression sequences and the double-headed arrow represents the portion of M13IX22 which is to be combined with M13IX42. The amber stop codon for biological selection and relevant restriction sites are also shown. M13IX42 (Figure 3B) is the vector used to clone the sense precursor portions (open box). Thick lines represent the pseudo-wild type (Ψ gVIII) and wild type (gVIII) gene VIII sequences. The double-headed arrow represents the portion of M13IX42 which is to be combined with M13IX22. The two amber stop codons and relevant restriction sites are also shown. Figure 3C shows the joining of vector population from sublibraries to form the functional surface expression vector M13IX. Figure 3D shows the generation of a surface expression library in a non-suppressor strain and the production of phage. The phage are used to infect a suppressor strain (Figure 3E) for surface expression and screening of the library.

Figure 4 is a schematic diagram of the vector used for generation of surface expression libraries from random oligonucleotide populations (M13IX30). The symbols are as described for Figure 3.

Figure 5 is the nucleotide sequence of M13IX42 (SEQ ID NO: 1).

Figure 6 is the nucleotide sequence of M13IX22 (SEQ ID NO: 2).

Figure 7 is the nucleotide sequence of M13IX30 (SEQ ID NO: 3).

5 Figure 8 is the nucleotide sequence of M13ED03 (SEQ ID NO: 4).

Figure 9 is the nucleotide sequence of M13IX421 (SEQ ID NO: 5).

10 Figure 10 is the nucleotide sequence of M13ED04 (SEQ ID NO: 6).

DETAILED DESCRIPTION OF THE INVENTION

This invention is directed to a simple and inexpensive method for synthesizing and expressing oligonucleotides having a desirable bias of random codons using individual monomers. The method is advantageous in that individual monomers are used instead of triplets and by synthesizing only a non-degenerate subset of all triplets, codon redundancy is alleviated. Thus, the oligonucleotides synthesized represent a large proportion of possible random triplet sequences which can be obtained. The oligonucleotides can be expressed, for example, on the surface of filamentous bacteriophage in a form which does not alter phage viability or impose biological selections against certain peptide sequences.

15
20
25 The oligonucleotides produced are therefore useful for generating an unlimited number of pharmacological and research products.

In one embodiment, the invention entails the sequential coupling of monomers to produce oligonucleotides with a desirable bias of random codons. The coupling reactions for the randomization of twenty
5 codons which specify the amino acids of the genetic code are performed in ten different reaction vessels. Each reaction vessel contains a support on which the monomers for two different codons are coupled in three sequential reactions. One of the reactions couples an equal mixture
10 of two monomers such that the final product has two different codon sequences. The codons are randomized by removing the supports from the reaction vessels and mixing them to produce a single batch of supports containing all twenty codons at a particular position.
15 Synthesis at the next codon position proceeds by equally dividing the mixed batch of supports into ten reaction vessels as before and sequentially coupling the monomers for each pair of codons. The supports are again mixed to randomize the codons at the position just synthesized.
20 The cycle of coupling, mixing and dividing continues until the desired number of codon positions have been randomized. After the last position has been randomized, the oligonucleotides with random codons are cleaved from the support. The random oligonucleotides can then be
25 expressed, for example, on the surface of filamentous bacteriophage as gene VIII-peptide fusion proteins. Alternative genes can be used as well.

In its broadest form, the invention provides a diverse population of synthetic oligonucleotides
30 contained in vectors so as to be expressible in cells. Such populations of diverse oligonucleotides can be fully random at one or more codon sites or can be fully defined at one or more site, so long as at least one site the codons are randomly variable. The populations of
35 oligonucleotides can be expressed as fusion products in

combination with surface proteins of filamentous bacteriophage, such as M13, as with gene VIII. The vectors can be transfected into a plurality of cells, such as the procaryote E. coli.

5 The diverse population of oligonucleotides can be formed by randomly combining first and second precursor populations, each precursor population having a desirable bias of random codon sequences. Methods of synthesizing and expressing the diverse population of expressible
10 oligonucleotides are also provided.

In a preferred embodiment, two populations of random oligonucleotides are synthesized. The oligonucleotides within each population encode a portion of the final oligonucleotide which is to be expressed.
15 Oligonucleotides within one population encode the carboxy terminal portion of the expressed oligonucleotides. These oligonucleotides are cloned in frame with a gene VIII (gVIII) sequence so that translation of the sequence produces peptide fusion proteins. The second population
20 of oligonucleotides are cloned into a separate vector. Each oligonucleotide within this population encodes the anti-sense of the amino terminal portion of the expressed oligonucleotides. This vector also contains the elements necessary for expression. The two vectors containing the
25 random oligonucleotides are combined such that the two precursor oligonucleotide portions are joined together at random to form a population of larger oligonucleotides derived from two smaller portions. The vectors contain selectable markers to ensure maximum efficiency in
30 joining together the two oligonucleotide populations. A mechanism also exists to control the expression of gVIII-peptide fusion proteins during library construction and screening.

As used herein, the term "monomer" or "nucleotide monomer" refers to individual nucleotides used in the chemical synthesis of oligonucleotides. Monomers that can be used include both the ribo- and deoxyribo- forms of each of the five standard nucleotides (derived from the bases adenine (A or dA, respectively), guanine (G or dG), cytosine (C or dC), thymine (T) and uracil (U)). Derivatives and precursors of bases such as inosine which are capable of supporting polypeptide biosynthesis are also included as monomers. Also included are chemically modified nucleotides, for example, one having a reversible blocking agent attached to any of the positions on the purine or pyrimidine bases, the ribose or deoxyribose sugar or the phosphate or hydroxyl moieties of the monomer. Such blocking groups include, for example, dimethoxytrityl, benzoyl, isobutyryl, beta-cyanoethyl and diisopropylamine groups, and are used to protect hydroxyls, exocyclic amines and phosphate moieties. Other blocking agents can also be used and are known to one skilled in the art.

As used herein, the term "tuplet" refers to a group of elements of a definable size. The elements of a tuplet as used herein are nucleotide monomers. For example, a tuplet can be a dinucleotide, a trinucleotide or can also be four or more nucleotides.

As used herein, the term "codon" or "triplet" refers to a tuplet consisting of three adjacent nucleotide monomers which specify one of the twenty naturally occurring amino acids found in polypeptide biosynthesis. The term also includes nonsense, or stop, codons which do not specify any amino acid.

"Random codons" or "randomized codons," as used herein, refers to more than one codon at a position within a collection of oligonucleotides. The number of different codons can be from two to twenty at any particular position. "Randomized oligonucleotides," as used herein, refers to a collection of oligonucleotides with random codons at one or more positions. "Random codon sequences" as used herein means that more than one codon position within a randomized oligonucleotide contains random codons. For example, if randomized oligonucleotides are six nucleotides in length (i.e., two codons) and both the first and second codon positions are randomized to encode all twenty amino acids, then a population of oligonucleotides having random codon sequences with every possible combination of the twenty triplets in the first and second position makes up the above population of randomized oligonucleotides. The number of possible codon combinations is 20^2 . Likewise, if randomized oligonucleotides of fifteen nucleotides in length are synthesized which have random codon sequences at all positions encoding all twenty amino acids, then all triplets coding for each of the twenty amino acids will be found in equal proportions at every position. The population constituting the randomized oligonucleotides will contain 20^{15} different possible species of oligonucleotides. "Random tuplets," or "randomized tuplets" are defined analogously.

As used herein, the term "bias" refers to a preference. It is understood that there can be degrees of preference or bias toward codon sequences which encode particular amino acids. For example, an oligonucleotide whose codon sequences do not preferably encode particular amino acids is unbiased and therefore completely random. The oligonucleotide codon sequences can also be biased toward predetermined codon sequences or codon frequencies

and while still diverse and random, will exhibit codon sequences biased toward a defined, or preferred, sequence. "A desirable bias of random codon sequences" as used herein, refers to the predetermined degree of bias which can be selected from totally random to essentially, but not totally, defined (or preferred). There must be at least one codon position which is variable, however.

As used herein, the term "support" refers to a solid phase material for attaching monomers for chemical synthesis. Such support is usually composed of materials such as beads of control pore glass but can be other materials known to one skilled in the art. The term is also meant to include one or more monomers coupled to the support for additional oligonucleotide synthesis reactions.

As used herein, the terms "coupling" or "condensing" refers to the chemical reactions for attaching one monomer to a second monomer or to a solid support. Such reactions are known to one skilled in the art and are typically performed on an automated DNA synthesizer such as a MilliGen/Bioscience Cyclone Plus Synthesizer using procedures recommended by the manufacturer. "Sequentially coupling" as used herein, refers to the stepwise addition of monomers.

A method of synthesizing oligonucleotides having random tuplets using individual monomers is described. The method consists of several steps, the first being synthesis of a nucleotide tuplet for each tuplet to be randomized. As described here and below, a nucleotide triplet (i.e., a codon) will be used as a specific example of a tuplet. Any size tuplet will work using the methods disclosed herein, and one skilled in the art

would know how to use the methods to randomize tuplets of any size.

If the randomization of codons specifying all twenty amino acids is desired at a position, then twenty
 5 different codons are synthesized. Likewise, if randomization of only ten codons at a particular position is desired then those ten codons are synthesized. Randomization of codons from two to sixty-four can be accomplished by synthesizing each desired triplet.
 10 Preferably, randomization of from two to twenty codons is used for any one position because of the redundancy of the genetic code. The codons selected at one position do not have to be the same codons selected at the next position. Additionally, the sense or anti-sense sequence
 15 oligonucleotide can be synthesized. The process therefore provides for randomization of any desired codon position with any number of codons.

Codons to be randomized are synthesized sequentially by coupling the first monomer of each codon to separate
 20 supports. The supports for the synthesis of each codon can, for example, be contained in different reaction vessels such that one reaction vessel corresponds to the monomer coupling reactions for one codon. As will be used here and below, if twenty codons are to be
 25 randomized, then twenty reaction vessels can be used in independent coupling reactions for the first twenty monomers of each codon. Synthesis proceeds by sequentially coupling the second monomer of each codon to the first monomer to produce a dimer, followed by
 30 coupling the third monomer for each codon to each of the above-synthesized dimers to produce a trimer (Figure 1, step 1, where M_1 , M_2 and M_3 represent the first, second and third monomer, respectively, for each codon to be randomized).

Following synthesis of the first codons from individual monomers, the randomization is achieved by mixing the supports from all twenty reaction vessels which contain the individual codons to be randomized.

- 5 The solid phase support can be removed from its vessel and mixed to achieve a random distribution of all codon species within the population (Figure 1, step 2). The mixed population of supports, constituting all codon species, are then redistributed into twenty independent
- 10 reaction vessels (Figure 1, step 3). The resultant vessels are all identical and contain equal portions of all twenty codons coupled to a solid phase support.

- For randomization of the second position codon, synthesis of twenty additional codons is performed in
- 15 each of the twenty reaction vessels produced in step 3 as the condensing substrates of step 1 (Figure 1, step 4). Steps 1 and 4 are therefore equivalent except that step 4 uses the supports produced by the previous synthesis cycle (steps 1 through 3) for codon synthesis whereas
- 20 step 1 is the initial synthesis of the first codon in the oligonucleotide. The supports resulting from step 4 will each have two codons attached to them (i.e., a hexanucleotide) with the codon at the first position being any one of twenty possible codons (i.e., random)
- 25 and the codon at the second position being one of the twenty possible codons.

- For randomization of the codon at the second position and synthesis of the third position codon, steps 2 through 4 are again repeated. This process yields in
- 30 each vessel a three codon oligonucleotide (i.e., 9 nucleotides) with codon positions 1 and 2 randomized and position three containing one of the twenty possible codons. Steps 2 through 4 are repeated to randomize the third position codon and synthesize the codon at the next

position. The process is continued until an oligonucleotide of the desired length is achieved. After the final randomization step, the oligonucleotide can be cleaved from the supports and isolated by methods known to one skilled in the art. Alternatively, the oligonucleotides can remain on the supports for use in methods employing probe hybridization.

The diversity of codon sequences, i.e., the number of different possible oligonucleotides, which can be obtained using the methods of the present invention, is extremely large and only limited by the physical characteristics of available materials. For example, a support composed of beads of about 100 μm in diameter will be limited to about 10,000 beads/reaction vessel using a 1 μM reaction vessel containing 25 mg of beads. This size bead can support about 1×10^7 oligonucleotides per bead. Synthesis using separate reaction vessels for each of the twenty amino acids will produce beads in which all the oligonucleotides attached to an individual bead are identical. The diversity which can be obtained under these conditions is approximately 10^7 copies of 10,000 x 20 or 200,000 different random oligonucleotides. The diversity can be increased, however, in several ways without departing from the basic methods disclosed herein. For example, the number of possible sequences can be increased by decreasing the size of the individual beads which make up the support. A bead of about 30 μm in diameter will increase the number of beads per reaction vessel and therefore the number of oligonucleotides synthesized. Another way to increase the diversity of oligonucleotides with random codons is to increase the volume of the reaction vessel. For example, using the same size bead, a larger volume can contain a greater number of beads than a smaller vessel and therefore support the synthesis of a greater number

of oligonucleotides. Increasing the number of codons coupled to a support in a single reaction vessel also increases the diversity of the random oligonucleotides. The total diversity will be the number of codons coupled per vessel raised to the number of codon positions synthesized. For example, using ten reaction vessels, each synthesizing two codons to randomize a total of twenty codons, the number of different oligonucleotides of ten codons in length per 100 μm bead can be increased where each bead will contain about 2^{10} or 1×10^3 different sequences instead of one. One skilled in the art will know how to modify such parameters to increase the diversity of oligonucleotides with random codons.

A method of synthesizing oligonucleotides having random codons at each position using individual monomers wherein the number of reaction vessels is less than the number of codons to be randomized is also described. For example, if twenty codons are to be randomized at each position within an oligonucleotide population, then ten reaction vessels can be used. The use of a smaller number of reaction vessels than the number of codons to be randomized at each position is preferred because the smaller number of reaction vessels is easier to manipulate and results in a greater number of possible oligonucleotides synthesized.

The use of a smaller number of reaction vessels for random synthesis of twenty codons at a desired position within an oligonucleotide is similar to that described above using twenty reaction vessels except that each reaction vessel can contain the synthesis products of more than one codon. For example, step one synthesis using ten reaction vessels proceeds by coupling about two different codons on supports contained in each of ten reaction vessels. This is shown in Figure 2 where each

of the two codons coupled to a different support can consist of the following sequences: (1) (T/G)TT for Phe and Val; (2) (T/C)CT for Ser and Pro; (3) (T/C)AT for Tyr and His; (4) (T/C)GT for Cys and Arg; (5) (C/A)TG for Leu and Met; (6) (C/G)AG for Gln and Glu; (7) (A/G)CT for Thr and Ala; (8) (A/G)AT for Asn and Asp; (9) (T/G)GG for Trp and Gly and (10) A(T/A)A for Ile and Cys. The slash (/) signifies that a mixture of the monomers indicated on each side of the slash are used as if they were a single monomer in the indicated coupling step. The antisense sequence for each of the above codons can be generated by synthesizing the complementary sequence. For example, the antisense for Phe and Val can be AA(C/A). The amino acids encoded by each of the above pairs of sequences are given as the standard three letter nomenclature.

Coupling of the monomers in this fashion will yield codons specifying all twenty of the naturally occurring amino acids attached to supports in ten reaction vessels. However, the number of individual reaction vessels to be used will depend on the number of codons to be randomized at the desired position and can be determined by one skilled in the art. For example, if ten codons are to be randomized, then five reaction vessels can be used for coupling. The codon sequences given above can be used for this synthesis as well. The sequences of the codons can also be changed to incorporate or be replaced by any of the additional forty-four codons which constitutes the genetic code.

The remaining steps of synthesis of oligonucleotides with random codons using a smaller number of reaction vessels are as outlined above for synthesis with twenty reaction vessels except that the mixing and dividing steps are performed with supports from about half the

number of reaction vessels. These remaining steps are shown in Figure 2 (steps 2 through 4).

Oligonucleotides having at least one specified
tuplet at a predetermined position and the remaining
5 positions having random tuplets can also be synthesized
using the methods described herein. The synthesis steps
are similar to those outlined above using twenty or less
reaction vessels except that prior to synthesis of the
specified codon position, the dividing of the supports
10 into separate reaction vessels for synthesis of different
codons is omitted. For example, if the codon at the
second position of the oligonucleotide is to be
specified, then following synthesis of random codons at
the first position and mixing of the supports, the mixed
15 supports are not divided into new reaction vessels but,
instead, can be contained in a single reaction vessel to
synthesize the specified codon. The specified codon is
synthesized sequentially from individual monomers as
described above. Thus, the number of reaction vessels
20 can be increased or decreased at each step to allow for
the synthesis of a specified codon or a desired number of
random codons.

Following codon synthesis, the mixed supports are
divided into individual reaction vessels for synthesis of
25 the next codon to be randomized (Figure 1, step 3) or can
be used without separation for synthesis of a consecutive
specified codon. The rounds of synthesis can be repeated
for each codon to be added until the desired number of
positions with predetermined or randomized codons are
30 obtained.

Synthesis of oligonucleotides with the first
position codon being specified can also be synthesized
using the above method. In this case, the first position

codon is synthesized from the appropriate monomers. The supports are divided into the required number of reaction vessels needed for synthesis of random codons at the second position and the rounds of synthesis, mixing and
 5 dividing are performed as described above.

A method of synthesizing oligonucleotides having tuplets which are diverse but biased toward a predetermined sequence is also described herein. This method employs two reaction vessels, one vessel for the
 10 synthesis of a predetermined sequence and the second vessel for the synthesis of a random sequence. This method is advantageous to use when a significant number of codon positions, for example, are to be of a specified sequence since it alleviates the use of multiple reaction
 15 vessels. Instead, a mixture of four different monomers such as adenine, guanine, cytosine and thymine nucleotides are used for the first and second monomers in the codon. The codon is completed by coupling a mixture of a pair of monomers of either guanine and thymine or
 20 cytosine and adenine nucleotides at the third monomer position. In the second vessel, nucleotide monomers are coupled sequentially to yield the predetermined codon sequence. Mixing of the two supports yields a population of oligonucleotides containing both the predetermined
 25 codon and the random codons at the desired position. Synthesis can proceed by using this mixture of supports in a single reaction vessel, for example, for coupling additional predetermined codons or, further dividing the mixture into two reaction vessels for synthesis of
 30 additional random codons.

The two reaction vessel method can be used for codon synthesis within an oligonucleotide with a predetermined tuplet sequence by dividing the support mixture into two portions at the desired codon position to be randomized.

Additionally, this method allows for the extent of randomization to be adjusted. For example, unequal mixing or dividing of the two supports will change the fraction of codons with predetermined sequences compared to those with random codons at the desired position. Unequal mixing and dividing of supports can be useful when there is a need to synthesize random codons at a significant number of positions within an oligonucleotide of a longer or shorter length.

10 The extent of randomization can also be adjusted by using unequal mixtures of monomers in the first, second and third monomer coupling steps of the random codon position. The unequal mixtures can be in any or all of the coupling steps to yield a population of codons enriched in sequences reflective of the monomer proportions.

 Synthesis of randomized oligonucleotides is performed using methods well known to one skilled in the art. Linear coupling of monomers can, for example, be accomplished using phosphoramidite chemistry with a MilliGen/Biosearch Cyclone Plus automated synthesizer as described by the manufacturer (Millipore, Burlington, MA). Other chemistries and automated synthesizers can be employed as well and are known to one skilled in the art.

25 Synthesis of multiple codons can be performed without modification to the synthesizer by separately synthesizing the codons in individual sets of reactions. Alternatively, modification of an automated DNA synthesizer can be performed for the simultaneous synthesis of codons in multiple reaction vessels.

In one embodiment, the invention provides a plurality of procaryotic cells containing a diverse population of expressible oligonucleotides operationally linked to expression elements, the expressible

5 oligonucleotides having a desirable bias of random codon sequences produced from diverse combinations of first and second oligonucleotides having a desirable bias of random sequences. The invention provides for a method for constructing such a plurality of procaryotic cells as

10 well.

The oligonucleotides synthesized by the above methods can be used to express a plurality of random peptides which are unbiased, diverse but biased toward a predetermined sequence or which contain at least one

15 specified codon at a predetermined position. The need will determine which type of oligonucleotide is to be expressed to give the resultant population of random peptides and is known to one skilled in the art. Expression can be performed in any compatible vector/host

20 system. Such systems include, for example, plasmids or phagemids in procaryotes such as E. coli, yeast systems, and other eucaryotic systems such as mammalian cells, but will be described herein in context with its presently preferred embodiment, i.e. expression on the surface of

25 filamentous bacteriophage. Filamentous bacteriophage can be, for example, M13, f1 and fd. Such phage have circular single-stranded genomes and double strand replicative DNA forms. Additionally, the peptides can also be expressed in soluble or secreted form depending

30 on the need and the vector/host system employed.

Expression of random peptides on the surface of M13 can be accomplished, for example, using the vector system shown in Figure 3. Construction of the vectors enabling one of ordinary skill to make them are explicitly set out

in Examples I and II. The complete nucleotide sequences are given in Figures 5, 6 and 7 (SEQ ID NOS: 1, 2 and 3, respectively). This system produces random oligonucleotides functionally linked to expression
5 elements and to gVIII by combining two smaller oligonucleotide portions contained in separate vectors into a single vector. The diversity of oligonucleotide species obtained by this system or others described herein can be 5×10^7 or greater. Diversity of less than
10 5×10^7 can also be obtained and will be determined by the need and type of random peptides to be expressed. The random combination of two precursor portions into a larger oligonucleotide increases the diversity of the population several fold and has the added advantage of
15 producing oligonucleotides larger than what can be synthesized by standard methods. Additionally, although the correlation is not known, when the number of possible paths an oligonucleotide can take during synthesis such as described herein is greater than the number of beads,
20 then there will be a correlation between the synthesis path and the sequences obtained. By combining oligonucleotide populations which are synthesized separately, this correlation will be destroyed. Therefore, any bias which may be inherent in the
25 synthesis procedures will be alleviated by joining two precursor portions into a contiguous random oligonucleotide.

Populations of precursor oligonucleotides to be combined into an expressible form are each cloned into
30 separate vectors. The two precursor portions which make up the combined oligonucleotide corresponds to the carboxy and amino terminal portions of the expressed peptide. Each precursor oligonucleotide can encode either the sense or anti-sense and will depend on the
35 orientation of the expression elements and the gene

encoding the fusion portion of the protein as well as the mechanism used to join the two precursor oligonucleotides. For the vectors shown in Figure 3, precursor oligonucleotides corresponding to the carboxy terminal portion of the peptide encode the sense strand. Those corresponding to the amino terminal portion encode the anti-sense strand. Oligonucleotide populations are inserted between the Eco RI and Sac I restriction enzyme sites in M13IX22 and M13IX42 (Figure 3A and B). M13IX42 (SEQ ID NO: 1) is the vector used for sense strand precursor oligonucleotide portions and M13IX22 (SEQ ID NO: 2) is used for anti-sense precursor portions.

The populations of randomized oligonucleotides inserted into the vectors are synthesized with Eco RI and Sac I recognition sequences flanking opposite ends of the random codon sequences. The sites allow annealing and ligation of these single strand oligonucleotides into a double stranded vector restricted with Eco RI and Sac I. Alternatively, the oligonucleotides can be inserted into the vector by standard mutagenesis methods. In this latter method, single stranded vector DNA is isolated from the phage and annealed with random oligonucleotides having known sequences complementary to vector sequences. The oligonucleotides are extended with DNA polymerase to produce double stranded vectors containing the randomized oligonucleotides.

The vector used for sense strand oligonucleotide portions, M13IX42 (Figure 3B) contains down-stream and in frame with the Eco RI and Sac I restriction sites a sequence encoding the pseudo-wild type gVIII product. This gene encodes the wild type M13 gVIII amino acid sequence but has been changed at the nucleotide level to reduce homologous recombination with the wild type gVIII contained on the same vector. The wild type gVIII is

present to ensure that at least some functional, non-fusion coat protein will be produced. The inclusion of a wild type gVIII therefore reduces the possibility of non-viable phage production and biological selection against certain peptide fusion proteins. Differential regulation of the two genes can also be used to control the relative ratio of the pseudo and wild type proteins.

Also contained downstream and in frame with the Eco RI and Sac I restriction sites is an amber stop codon. The mutation is located six codons downstream from Sac I and therefore lies between the inserted oligonucleotides and the gVIII sequence. As was the function of the wild type gVIII, the amber stop codon also reduces biological selection when combining precursor portions to produce expressible oligonucleotides. This is accomplished by using a non-suppressor (sup O) host strain because non-suppressor strains will terminate expression after the oligonucleotide sequences but before the pseudo gVIII sequences. Therefore, the pseudo gVIII will never be expressed on the phage surface under these circumstances. Instead, only soluble peptides will be produced. Expression in a non-suppressor strain can be advantageously utilized when one wishes to produce large populations of soluble peptides. Stop codons other than amber, such as opal and ochre, or molecular switches, such as inducible repressor elements, can also be used to unlink peptide expression from surface expression. Additional controls exist as well and are described below.

The vector used for anti-sense strand oligonucleotide portions, M13IX22, (Figure 3A), contains the expression elements for the peptide fusion proteins. Upstream and in frame with the Sac I and Eco RI sites in this vector is a leader sequence for surface expression.

A ribosome binding site and Lac Z promoter/operator elements are present for transcription and translation of the peptide fusion proteins.

Both vectors contain a pair of Fok I restriction
 5 enzyme sites (Figure 3 A and B) for joining together two precursor oligonucleotide portions and their vector sequences. One site is located at the ends of each precursor oligonucleotide which is to be joined. The second Fok I site within the vectors is located at the
 10 end of the vector sequences which are to be joined. The 5' overhang of this second Fok I site has been altered to encode a sequence which is not found in the overhangs produced at the first Fok I site within the oligonucleotide portions. The two sites allow the
 15 cleavage of each circular vector into two portions and subsequent ligation of essential components within each vector into a single circular vector where the two oligonucleotide precursor portions form a contiguous sequence (Figure 3C). Non-compatible overhangs produced
 20 at the two Fok I sites allows optimal conditions to be selected for performing concatemization or circularization reactions for joining the two vector portions. Such selection of conditions can be used to govern the reaction order and therefore increase the
 25 efficiency of joining.

Fok I is a restriction enzyme whose recognition sequence is distal to the point of cleavage. Distal placement of the recognition sequence in its location to the cleavage point is important since if the two were
 30 superimposed within the oligonucleotide portions to be combined, it would lead to an invariant codon sequence at the juncture. To alleviate the formation of invariant codons at the juncture, Fok I recognition sequences can be placed outside of the random codon sequence and still

be used to restrict within the random sequence.

Subsequent annealing of the single-strand overhangs produced by Fok I and ligation of the two oligonucleotide precursor portions allows the juncture to be formed. A

5 variety of restriction enzymes restrict DNA by this mechanism and can be used instead of Fok I to join precursor oligonucleotides without creating invariant codon sequences. Such enzymes include, for example, Alw I, Bbu I, Bsp MI, Hga I, Hph I, Mbo II, Mnl I, Ple I and
10 Sfa NI. One skilled in the art knows how to substitute Fok I recognition sequences for alternative enzyme recognition sequences such as those above, and use the appropriate enzyme for joining precursor oligonucleotide portions.

15 Although the sequences of the precursor oligonucleotides are random and will invariably have oligonucleotides within the two precursor populations whose sequences are sufficiently complementary to anneal after cleavage, the efficiency of annealing can be
20 increased by insuring that the single-strand overhangs within one precursor population will have a complementary sequence within the second precursor population. This can be accomplished by synthesizing a non-degenerate series of known sequences at the Fok I cleavage site
25 coding for each of the twenty amino acids. Since the Fok I cleavage site contains a four base overhang, forty different sequences are needed to randomly encode all twenty amino acids. For example, if two precursor populations of ten codons in length are to be combined,
30 then after the ninth codon position is synthesized, the mixed population of supports are divided into forty reaction vessels for each of the populations and complementary sequences for each of the corresponding reaction vessels between populations are independently
35 synthesized. The sequences are shown in Tables III and

VI of Example I where the oligonucleotides on columns 1R through 40R form complementary overhangs with the oligonucleotides on the corresponding columns 1L through 40L once cleaved. The degenerate X positions in Table VI
 5 are necessary to maintain the reading frame once the precursor oligonucleotide portions are joined. However, use of restriction enzymes which produce a blunt end, such as Mnl I can be alternatively used in place of Fok I to alleviate the degeneracy introduced in maintaining the
 10 reading frame.

The last feature exhibited by each of the vectors is an amber stop codon located in an essential coding sequence within the vector portion lost during combining (Figure 3C). The amber stop codon is present to select
 15 for viable phage produced from only the proper combination of precursor oligonucleotides and their vector sequences into a single vector species. Other non-sense mutations or selectable markers can work as well.

20 The combining step randomly brings together different precursor oligonucleotides within the two populations into a single vector (Figure 3C; M13IX). The vector sequences donated from each independent vector, M13IX22 and M13IX42, are necessary for production of
 25 viable phage. Also, since the expression elements are contained in M13IX22 and the gVIII sequences are contained in M13IX42, expression of functional gVIII-peptide fusion proteins cannot be accomplished until the sequences are linked as shown in M13IX.

30 The combining step is performed by restricting each population of vectors containing randomized oligonucleotides with Fok I, mixing and ligating (Figure 3C). Any vectors generated which contain an amber stop

codon will not produce viable phage when introduced into a non-suppressor strain (Figure 3D). Therefore, only the sequences which do not contain an amber stop codon will make up the final population of vectors contained in the library. These vector sequences are the sequences required for surface expression of randomized peptides. By analogous methodology, more than two vector portions can be combined into a single vector which expresses random peptides.

10 The invention provides for a method of selecting peptides capable of being bound by a ligand binding protein from a population of random peptides by (a) operationally linking a diverse population of first oligonucleotides having a desirable bias of random codon sequences to a first vector; (b) operationally linking a diverse population of second oligonucleotides having a desirable bias of random codon sequences to a second vector; (c) combining the vector products of steps (a) and (b) under conditions where said populations of first and second oligonucleotides are joined together into a population of combined vectors; (d) introducing said population of combined vectors into a compatible host under conditions sufficient for expressing said population of random peptides; and (e) determining the peptides which bind to said binding protein. The invention also provides for determining the encoding nucleic acid sequence of such peptides as well.

Surface expression of the random peptide library is performed in an amber suppressor strain. As described above, the amber stop codon between the random codon sequence and the gVIII sequence unlinks the two components in a non-suppressor strain. Isolating the phage produced from the non-suppressor strain and infecting a suppressor strain will link the random codon

sequences to the gVIII sequence during expression (Figure 3E). Culturing the suppressor strain after infection allows the expression of all peptide species within the library as gVIII-peptide fusion proteins. Alternatively, 5 the DNA can be isolated from the non-suppressor strain and then introduced into a suppressor strain to accomplish the same effect.

The level of expression of gVIII-peptide fusion proteins can additionally be controlled at the 10 transcriptional level. The gVIII-peptide fusion proteins are under the inducible control of the Lac Z promoter/operator system. Other inducible promoters can work as well and are known by one skilled in the art. For high levels of surface expression, the suppressor 15 library is cultured in an inducer of the Lac Z promoter such as isopropylthio- β -galactoside (IPTG). Inducible control is beneficial because biological selection against non-functional gVIII-peptide fusion proteins can be minimized by culturing the library under non- 20 expressing conditions. Expression can then be induced only at the time of screening to ensure that the entire population of oligonucleotides within the library are accurately represented on the phage surface. Also this can be used to control the valency of the peptide on the 25 phage surface.

The surface expression library is screened for specific peptides which bind ligand binding proteins by standard affinity isolation procedures. Such methods include, for example, panning, affinity chromatography 30 and solid phase blotting procedures. Panning as described by Parmley and Smith, Gene 73:305-318 (1988), which is incorporated herein by reference, is preferred because high titers of phage can be screened easily, quickly and in small volumes. Furthermore, this

procedure can select minor peptide species within the population, which otherwise would have been undetectable, and amplified to substantially homogenous populations. The selected peptide sequences can be determined by
 5 sequencing the nucleic acid encoding such peptides after amplification of the phage population.

The invention provides a plurality of procaryotic cells containing a diverse population of oligonucleotides having a desirable bias of random codon sequences that
 10 are operationally linked to expression sequences. The invention provides for methods of constructing such populations of cells as well.

Random oligonucleotides synthesized by any of the methods described previously can also be expressed on the
 15 surface of filamentous bacteriophage, such as M13, for example, without the joining together of precursor oligonucleotides. A vector such as that shown in Figure 4, M13IX30, can be used. This vector exhibits all the functional features of the combined vector shown in
 20 Figure 3C for surface expression of gVIII-peptide fusion proteins. The complete nucleotide sequence for M13IX30 (SEQ ID NO: 3) is shown in Figure 7.

M13IX30 contains a wild type gVIII for phage viability and a pseudo gVIII sequence for peptide
 25 fusions. The vector also contains in frame restriction sites for cloning random peptides. The cloning sites in this vector are Xho I, Stu I and Spe I. Oligonucleotides should therefore be synthesized with the appropriate complementary ends for annealing and ligation or
 30 insertional mutagenesis. Alternatively, the appropriate termini can be generated by PCR technology. Between the restriction sites and the pseudo gVIII sequence is an in-frame amber stop codon, again, ensuring complete

viability of phage in constructing and manipulating the library. Expression and screening is performed as described above for the surface expression library of oligonucleotides generated from precursor portions.

5 Thus, the invention provides a method of selecting peptides capable of being bound by a ligand binding protein from a population of random peptides by (a) operationally linking a diverse population of oligonucleotides having a desirable bias of random codon
10 sequences to expression elements; (b) introducing said population of vectors into a compatible host under conditions sufficient for expressing said population of random peptides; and (c) determining the peptides which bind to said binding protein. Also provided is a method
15 for determining the encoding nucleic acid sequence of such selected peptides.

The following examples are intended to illustrate, but not limit the invention.

20

EXAMPLE I

Isolation and Characterization of Peptide Ligands Generated From Right and Left Half Random Oligonucleotides

This example shows the synthesis of random oligonucleotides and the construction and expression of
25 surface expression libraries of the encoded randomized peptides. The random peptides of this example derive from the mixing and joining together of two random oligonucleotides. Also demonstrated is the isolation and characterization of peptide ligands and their
30 corresponding nucleotide sequence for specific binding proteins.

Synthesis of Random Oligonucleotides

The synthesis of two randomized oligonucleotides which correspond to smaller portions of a larger randomized oligonucleotide is shown below. Each of the two smaller portions make up one-half of the larger oligonucleotide. The population of randomized oligonucleotides constituting each half are designated the right and left half. Each population of right and left halves are ten codons in length with twenty random codons at each position. The right half corresponds to the sense sequence of the randomized oligonucleotides and encode the carboxy terminal half of the expressed peptides. The left half corresponds to the anti-sense sequence of the randomized oligonucleotides and encode the amino terminal half of the expressed peptides. The right and left halves of the randomized oligonucleotide populations are cloned into separate vector species and then mixed and joined so that the right and left halves come together in random combination to produce a single expression vector species which contains a population of randomized oligonucleotides twenty codons in length. Electroporation of the vector population into an appropriate host produces filamentous phage which express the random peptides on their surface.

The reaction vessels for oligonucleotide synthesis were obtained from the manufacturer of the automated synthesizer (Millipore, Burlington, MA; supplier of MilliGen/Biosearch Cyclone Plus Synthesizer). The vessels were supplied as packages containing empty reaction columns (1 μ mole), frits, crimps and plugs (MilliGen/Biosearch catalog # GEN 860458). Derivatized and underivatized control pore glass, phosphoramidite nucleotides, and synthesis reagents were also obtained from MilliGen/Biosearch. Crimper and decrimper tools

were obtained from Fisher Scientific Co., Pittsburgh, PA (Catalog numbers 06-406-20 and 06-406-25A, respectively).

Ten reaction columns were used for right half synthesis of random oligonucleotides ten codons in length. The oligonucleotides have 5 monomers at their 3' end of the sequence 5'GAGCT3' and 8 monomers at their 5' end of the sequence 5'AATTCCAT3'. The synthesizer was fitted with a column derivatized with a thymine nucleotide (T-column, MilliGen/Biosearch # 0615.50) and was programmed to synthesize the sequences shown in Table I for each of ten columns in independent reaction sets. The sequence of the last three monomers (from right to left since synthesis proceeds 3' to 5') encode the indicated amino acids:

15

Table I

	<u>Column</u>	<u>Sequence</u> (5' to 3')	<u>Amino Acids</u>
	column 1R	(T/G) TTGAGCT	Phe and Val
20	column 2R	(T/C) CTGAGCT	Ser and Pro
	column 3R	(T/C) ATGAGCT	Tyr and His
	column 4R	(T/C) GTGAGCT	Cys and Arg
	column 5R	(C/A) TGGAGCT	Leu and Met
	column 6R	(C/G) AGGAGCT	Gln and Glu
25	column 7R	(A/G) CTGAGCT	Thr and Ala
	column 8R	(A/G) ATGAGCT	Asn and Asp
	column 9R	(T/G) GGGAGCT	Trp and Gly
	column 1R	A(T/A) AGAGCT	Ile and Cys

where the two monomers in parentheses denote a single monomer position within the codon and indicate that an equal mixture of each monomer was added to the reaction for coupling. The monomer coupling reactions for each

of the 10 columns were performed as recommended by the manufacturer (amidite version S1.06, # 8400-050990, scale 1 μ M). After the last coupling reaction, the columns were washed with acetonitrile and lyophilized to dryness.

5 Following synthesis, the plugs were removed from each column using a decrimper and the reaction products were poured into a single weigh boat. Initially the bead mass increases, due to the weight of the monomers, however, at later rounds of synthesis material is lost.

10 In either case, the material was equalized with underivatized control pore glass and mixed thoroughly to obtain a random distribution of all twenty codon species. The reaction products were then aliquotted into 10 new reaction columns by removing 25 mg of material at a time

15 and placing it into separate reaction columns. Alternatively, the reaction products can be aliquotted by suspending the beads in a liquid that is dense enough for the beads to remain dispersed, preferably a liquid that is equal in density to the beads, and then aliquoting

20 equal volumes of the suspension into separate reaction columns. The lip on the inside of the columns where the frits rest was cleared of material using vacuum suction with a syringe and 25 G needle. New frits were placed onto the lips, the plugs were fitted into the columns and

25 were crimped into place using a crimper.

Synthesis of the second codon position was achieved using the above 10 columns containing the random mixture of reaction products from the first codon synthesis. The monomer coupling reactions for the second codon position

30 are shown in Table II. An A in the first position means that any monomer can be programmed into the synthesizer. At that position, the first monomer position is not coupled by the synthesizer since the software assumes that the monomer is already attached to the column. An A

also denotes that the columns from the previous codon synthesis should be placed on the synthesizer for use in the present synthesis round. Reactions were again sequentially repeated for each column as shown in Table II and the reaction products washed and dried as described above.

Table II

	<u>Column</u>	<u>Sequence (5' to 3')</u>	<u>Amino Acids</u>
10	column 1R	(T/G) TTA	Phe and Val
	column 2R	(T/C) CTA	Ser and Pro
	column 3R	(T/C) ATA	Tyr and His
	column 4R	(T/C) GTA	Cys and Arg
	column 5R	(C/A) TGA	Leu and Met
15	column 6R	(C/G) AGA	Gln and Glu
	column 7R	(A/G) CTA	Thr and Ala
	column 8R	(A/G) ATA	Asn and Asp
	column 9R	(T/G) GGA	Trp and Gly
	column 10R	A(T/A) AA	Ile and Cys

20 Randomization of the second codon position was achieved by removing the reaction products from each of the columns and thoroughly mixing the material. The material was again divided into new reaction columns and prepared for monomer coupling reactions as described above.

25 Random synthesis of the next seven codons (positions 3 through 9) proceeded identically to the cycle described above for the second codon position and again used the monomer sequences of Table II. Each of the newly repacked columns containing the random mixture of
30 reaction products from synthesis of the previous codon position was used for the synthesis of the subsequent codon position. After synthesis of the codon at position

nine and mixing of the reaction products, the material was divided and repacked into 40 different columns and the monomer sequences shown in Table III were coupled to each of the 40 columns in independent reactions. The
 5 oligonucleotides from each of the 40 columns were mixed once more and cleaved from the control pore glass as recommended by the manufacturer.

Table III

	<u>Column</u>	<u>Sequence (5' to 3')</u>
10	column 1R	AATTCTTTTA
	column 2R	AATTCTGTTA
	column 3R	AATTCGTTTA
	column 4R	AATTCGGTTA
15	column 5R	AATTCTTCTA
	column 6R	AATTCTCCTA
	column 7R	AATTCGTCTA
	column 8R	AATTCGCCTA
	column 9R	AATTCTTATA
20	column 10R	AATTCTCATA
	column 11R	AATTCGTATA
	column 12R	AATTCGCATA
	column 13R	AATTCTTGTA
	column 14R	AATTCTCGTA
25	column 15R	AATTCGTGTA
	column 16R	AATTCGCGTA
	column 17R	AATTCTCTGA
	column 18R	AATTCTATGA
	column 19R	AATTCGCTGA
30	column 20R	AATTCGATGA
	column 21R	AATTCTCAGA
	column 22R	AATTCTGAGA
	column 23R	AATTCGCAGA
	column 24R	AATTCGGAGA
35	column 25R	AATTCTACTA

	column 26R	<u>AATTCTGCTA</u>
	column 27R	<u>AATTCGACTA</u>
	column 28R	<u>AATTCGGCTA</u>
	column 29R	<u>AATTCTAATA</u>
5	column 30R	<u>AATTCTGATA</u>
	column 31R	<u>AATTCGAATA</u>
	column 32R	<u>AATTCGGATA</u>
	column 33R	<u>AATTCTTGGA</u>
	column 34R	<u>AATTCTGGGA</u>
10	column 35R	<u>AATTCGTGGA</u>
	column 36R	<u>AATTCGGGGA</u>
	column 37R	<u>AATTCTATAA</u>
	column 38R	<u>AATTCTAAAA</u>
	column 39R	<u>AATTCGATAA</u>
15	column 40R	<u>AATTCGAAAA</u>

Left half synthesis of random oligonucleotides proceeded similarly to the right half synthesis. This half of the oligonucleotide corresponds to the anti-sense sequence of the encoded randomized peptides. Thus, the complementary sequence of the codons in Tables I through III are synthesized. The left half oligonucleotides also have 5 monomers at their 3' end of the sequence 5'GAGCT3' and 8 monomers at their 5' end of the sequence 5'AATTCCAT3'. The rounds of synthesis, washing, drying, mixing, and dividing are as described above.

For the first codon position, the synthesizer was fitted with a T-column and programmed to synthesize the sequences shown in Table IV for each of ten columns in independent reaction sets. As with right half synthesis, the sequence of the last three monomers (from right to left) encode the indicated amino acids:

Table IV

	<u>Column</u>	<u>Sequence (5' to 3')</u>	<u>Amino Acids</u>
5	column 1L	AA (A/C) GAGCT	Phe and Val
	column 2L	AG (A/G) GAGCT	Ser and Pro
	column 3L	AT (A/G) GAGCT	Tyr and His
	column 4L	AC (A/G) GAGCT	Cys and Arg
	column 5L	CA (G/T) GAGCT	Leu and Met
10	column 6L	CT (G/C) GAGCT	Gln and Glu
	column 7L	AG (T/C) GAGCT	Thr and Ala
	column 8L	AT (T/C) GAGCT	Asn and Asp
	column 9L	CC (A/C) GAGCT	Trp and Gly
	column 10L	T (A/T) TGAGCT	Ile and Cys

Following washing and drying, the plugs for each column
 15 were removed, mixed and aliquotted into ten new reaction
 columns as described above. Synthesis of the second
 codon position was achieved using these ten columns
 containing the random mixture of reaction products from
 the first codon synthesis. The monomer coupling
 20 reactions for the second codon position are shown in
 Table V.

Table V

	<u>Column</u>	<u>Sequence (5' to 3')</u>	<u>Amino Acids</u>
25	column 1L	AA (A/C) <u>A</u>	Phe and Val
	column 2L	AG (A/G) <u>A</u>	Ser and Pro
	column 3L	AT (A/G) <u>A</u>	Tyr and His
	column 4L	AC (A/G) <u>A</u>	Cys and Arg
	column 5L	CA (G/T) <u>A</u>	Leu and Met
30	column 6L	CT (G/C) <u>A</u>	Gln and Glu
	column 7L	AG (T/C) <u>A</u>	Thr and Ala

column 8L	AT(T/C) <u>A</u>	Asn and Asp
column 9L	CC(A/C) <u>A</u>	Trp and Gly
column 10L	T(A/T) <u>TA</u>	Ile and Cys

Again, randomization of the second codon position was
 5 achieved by removing the reaction products from each of
 the columns and thoroughly mixing the beads. The beads
 were repacked into ten new reaction columns.

Random synthesis of the next seven codon positions
 proceeded identically to the cycle described above for
 10 the second codon position and again used the monomer
 sequences of Table V. After synthesis of the codon at
 position nine and mixing of the reaction products, the
 material was divided and repacked into 40 different
 columns and the monomer sequences shown in Table VI were
 15 coupled to each of the 40 columns in independent
 reactions.

Table VI

	<u>Column</u>	<u>Sequence (5' to 3')</u>
20	column 1L	AATTCCATAAAAXXA
	column 2L	AATTCCATAAACXXA
	column 3L	AATTCCATAACAXXA
	column 4L	AATTCCATAACCXXA
	column 5L	AATTCCATAGAAXXA
25	column 6L	AATTCCATAGACXXA
	column 7L	AATTCCATAGGAXXA
	column 8L	AATTCCATAGGCXXA
	column 9L	AATTCCATATAAXXA
	column 10L	AATTCCATATACXXA
30	column 11L	AATTCCATATGAXXA
	column 12L	AATTCCATATGCXXA
	column 13L	AATTCCATACAAXXA
	column 14L	AATTCCATACACXXA

	column 15L	<u>AATTCCATACGAXXA</u>
	column 16L	<u>AATTCCATACGCXXA</u>
	column 17L	<u>AATTCCATCAGAXXA</u>
	column 18L	<u>AATTCCATCAGCXXA</u>
5	column 19L	<u>AATTCCATCATAXXA</u>
	column 20L	<u>AATTCCATCATCXXA</u>
	column 21L	<u>AATTCCATCTGAXXA</u>
	column 22L	<u>AATTCCATCTGCXXA</u>
	column 23L	<u>AATTCCATCTCAXXA</u>
10	column 24L	<u>AATTCCATCTCCXXA</u>
	column 25L	<u>AATTCCATAGTAXXA</u>
	column 26L	<u>AATTCCATAGTCXXA</u>
	column 27L	<u>AATTCCATAGCAXXA</u>
	column 28L	<u>AATTCCATAGCCXXA</u>
15	column 29L	<u>AATTCCATATTAXXA</u>
	column 30L	<u>AATTCCATATTCXXA</u>
	column 31L	<u>AATTCCATATCAXXA</u>
	column 32L	<u>AATTCCATATCCXXA</u>
	column 33L	<u>AATTCCATCCAAXXA</u>
20	column 34L	<u>AATTCCATCCACXXA</u>
	column 35L	<u>AATTCCATCCCAXXA</u>
	column 36L	<u>AATTCCATCCCCXXA</u>
	column 37L	<u>AATTCCATTATAXXA</u>
	column 38L	<u>AATTCCATTATCXXA</u>
25	column 39L	<u>AATTCCATTTTAXXA</u>
	column 40L	<u>AATTCCATTTTCXXA</u>

The first two monomers denoted by an "X" represent an equal mixture of all four nucleotides at that position. This is necessary to retain a relatively unbiased codon sequence at the junction between right and left half oligonucleotides. The above right and left half random oligonucleotides were cleaved and purified from the supports and used in constructing the surface expression libraries below.

Vector Construction

Two M13-based vectors, M13IX42 (SEQ ID NO: 1) and M13IX22 (SEQ ID NO: 2), were constructed for the cloning and propagation of right and left half populations of random oligonucleotides, respectively. The vectors were specially constructed to facilitate the random joining and subsequent expression of right and left half oligonucleotide populations. Each vector within the population contains one right and one left half oligonucleotide from the population joined together to form a single contiguous oligonucleotide with random codons which is twenty-two codons in length. The resultant population of vectors are used to construct a surface expression library.

M13IX42, or the right-half vector, was constructed to harbor the right half populations of randomized oligonucleotides. M13mp18 (Pharmacia, Piscataway, NJ) was the starting vector. This vector was genetically modified to contain, in addition to the encoded wild type M13 gene VIII already present in the vector: (1) a pseudo-wild type M13 gene VIII sequence with a stop codon (amber) placed between it and an Eco RI-Sac I cloning site for randomized oligonucleotides; (2) a pair of Fok I sites to be used for joining with M13IX22, the left-half vector; (3) a second amber stop codon placed on the opposite side of the vector than the portion being combined with the left-half vector; and (4) various other mutations to remove redundant restriction sites and the amino terminal portion of Lac Z.

The pseudo-wild type M13 gene VIII was used for surface expression of random peptides. The pseudo-wild type gene encodes the identical amino acid sequence as that of the wild type gene; however, the nucleotide

sequence has been altered so that only 63% identity exists between this gene and the encoded wild type gene VIII. Modification of the gene VIII nucleotide sequence used for surface expression reduces the possibility of homologous recombination with the wild type gene VIII contained on the same vector. Additionally, the wild type M13 gene VIII was retained in the vector system to ensure that at least some functional, non-fusion coat protein would be produced. The inclusion of wild type gene VIII therefore reduces the possibility of non-viable phage production from the random peptide fusion genes.

The pseudo-wild type gene VIII was constructed by chemically synthesizing a series of oligonucleotides which encode both strands of the gene. The oligonucleotides are presented in Table VII (SEQ ID NOS: 7 through 16).

TABLE VII

Pseudo-Wild Type Gene VIII Oligonucleotide Series

	<u>Top Strand</u> <u>Oligonucleotides</u>	<u>Sequence (5' to 3')</u>
20	VIII 03	GATCC TAG GCT GAA GGC GAT GAC CCT GCT AAG GCT GC
	VIII 04	A TTC AAT AGT TTA CAG GCA AGT GCT ACT GAG TAC A
25	VIII 05	TT GGC TAC GCT TGG GCT ATG GTA GTA GTT ATA GTT
	VIII 06	GGT GCT ACC ATA GGG ATT AAA TTA TTC AAA AAG TT
	VIII 07	T ACG AGC AAG GCT TCT TA
30	Bottom Strand	

Oligonucleotides

	VIII 08	AGC TTA AGA AGC CTT GCT CGT AAA CTT TTT GAA TAA TTT
5	VIII 09	AAT CCC TAT GGT AGC ACC AAC TAT AAC TAC TAC CAT
	VIII 10	AGC CCA AGC GTA GCC AAT GTA CTC AGT AGC ACT TG
	VIII 11	C CTG TAA ACT ATT GAA TGC AGC CTT AGC AGG GTC
10	VIII 12	ATC GCC TTC AGC CTA G

Except for the terminal oligonucleotides VIII 03 (SEQ ID NO: 7) and VIII 08 (SEQ ID NO: 12), the above oligonucleotides (oligonucleotides VIII 04-VIII 07 and 09-12 (SEQ ID NOS: 8 through 11 and 13 through 16)) were mixed at 200 ng each in 10 μ l final volume and phosphorylated with T4 polynucleotide Kinase (Pharmacia, Piscataway, NJ) with 1 mM ATP at 37°C for 1 hour. The reaction was stopped at 65°C for 5 minutes. Terminal oligonucleotides were added to the mixture and annealed into double-stranded form by heating to 65°C for 5 minutes, followed by cooling to room temperature over a period of 30 minutes. The annealed oligonucleotides were ligated together with 1.0 U of T4 DNA ligase (BRL). The annealed and ligated oligonucleotides yield a double-stranded DNA flanked by a Bam HI site at its 5' end and by a Hind III site at its 3' end. A translational stop codon (amber) immediately follows the Bam HI site. The gene VIII sequence begins with the codon GAA (Glu) two codons 3' to the stop codon. The double-stranded insert was phosphorylated using T4 DNA Kinase (Pharmacia, Piscataway, NJ) and ATP (10 mM Tris-HCl, pH 7.5, 10 mM MgCl₂) and cloned in frame with the Eco RI and Sac I sites within the M13 polylinker. To do so, M13mp18 was digested with Bam HI (New England Biolabs, Beverley, MA)

and Hind III (New England Biolabs) and combined at a molar ratio of 1:10 with the double-stranded insert. The ligations were performed at 16°C overnight in 1X ligase buffer (50 mM Tris-HCl, pH 7.8, 10 mM MgCl₂, 20 mM DTT, 1 mM ATP, 50 µg/ml BSA) containing 1.0 U of T4 DNA ligase (New England Biolabs). The ligation mixture was transformed into a host and screened for positive clones using standard procedures in the art.

Several mutations were generated within the right-half vector to yield functional M13IX42. The mutations were generated using the method of Kunkel et al., Meth. Enzymol. 154:367-382 (1987), which is incorporated herein by reference, for site-directed mutagenesis. The reagents, strains and protocols were obtained from a Bio Rad Mutagenesis kit (Bio Rad, Richmond, CA) and mutagenesis was performed as recommended by the manufacturer.

A Fok I site used for joining the right and left halves was generated 8 nucleotides 5' to the unique Eco RI site using the oligonucleotide 5'-CTCGAATTCGTACATCCTGGTCATAGC-3' (SEQ ID NO: 17). The second Fok I site retained in the vector is naturally encoded at position 3547; however, the sequence within the overhang was changed to encode CTTC. Two Fok I sites were removed from the vector at positions 239 and 7244 of M13mp18 as well as the Hind III site at the end of the pseudo gene VIII sequence using the mutant oligonucleotides 5'-CATTTTTGCAGATGGCTTAGA -3' (SEQ ID NO: 18) and 5'-TAGCATTAACGTCCAATA-3' (SEQ ID NO: 19), respectively. New Hind III and Mlu I sites were also introduced at position 3919 and 3951 of M13IX42. The oligonucleotides used for this mutagenesis had the sequences 5'-ATATATTTTAGTAAGCTTCATCTTCT-3' (SEQ ID NO: 20) and 5'-GACAAAGAACGCGTGAAAACCTT-3' (SEQ ID NO: 21), respectively.

The amino terminal portion of Lac Z was deleted by oligonucleotide-directed mutagenesis using the mutant oligonucleotide 5'-GCGGGCCTCTTCGCTATTGCTTAAGAAGCCTTGCT-3' (SEQ ID NO: 22). This deletion also removed a third
 5 M13mp18 derived Fok I site. The distance between the Eco RI and Sac I sites was increased to ensure complete double digestion by inserting a spacer sequence. The spacer sequence was inserted using the oligonucleotide 5'-TTCAGCCTAGGATCCGCCGAGCTCTCCTACCTGCGAATTCGTACATCC-3'
 10 (SEQ ID NO: 23). Finally, an amber stop codon was placed at position 4492 using the mutant oligonucleotide 5'-TGGATTATACTTCTA AATAATGGA-3' (SEQ ID NO: 24). The amber stop codon is used as a biological selection to ensure the proper recombination of vector sequences to bring
 15 together right and left halves of the randomized oligonucleotides. In constructing the above mutations, all changes made in a M13 coding region were performed such that the amino acid sequence remained unaltered. It should be noted that several mutations within M13mp18
 20 were found which differed from the published sequence. Where known, these sequence differences are recorded herein as found and therefore may not correspond exactly to the published sequence of M13mp18.

The sequence of the resultant vector, M13IX42, is
 25 shown in Figure 5 (SEQ ID NO: 1). Figure 3A also shows M13IX42 where each of the elements necessary for producing a surface expression library between right and left half randomized oligonucleotides is marked. The sequence between the two Fok I sites shown by the arrow
 30 is the portion of M13IX42 which is to be combined with a portion of the left-half vector to produce random oligonucleotides as fusion proteins of gene VIII.

M13IX22, or the left-half vector, was constructed to harbor the left half populations of randomized

oligonucleotides. This vector was constructed from M13mp19 (Pharmacia, Piscataway, NJ) and contains: (1) Two Fok I sites for mixing with M13IX42 to bring together the left and right halves of the randomized oligonucleotides; (2) sequences necessary for expression such as a promoter and signal sequence and translation initiation signals; (3) an Eco RI-Sac I cloning site for the randomized oligonucleotides; and (4) an amber stop codon for biological selection in bringing together right and left half oligonucleotides.

Of the two Fok I sites used for mixing M13IX22 with M13IX42, one is naturally encoded in M13mp18 and M13mp19 (at position 3547). As with M13IX42, the overhang within this naturally occurring Fok I site was changed to CTTC. The other Fok I site was introduced after construction of the translation initiation signals by site-directed mutagenesis using the oligonucleotide 5'-TAACACTCATTCCGGATGGAATTCTGGAGTCTGGGT-3' (SEQ ID NO: 25).

The translation initiation signals were constructed by annealing of overlapping oligonucleotides as described above to produce a double-stranded insert containing a 5' Eco RI site and a 3' Hind III site. The overlapping oligonucleotides are shown in Table VIII (SEQ ID NOS: 26 through 34) and were ligated as a double-stranded insert between the Eco RI and Hind III sites of M13mp18 as described for the pseudo gene VIII insert. The ribosome binding site (AGGAGAC) is located in oligonucleotide 015 (SEQ ID NO: 26) and the translation initiation codon (ATG) is the first three nucleotides of oligonucleotide 016 (SEQ ID NO: 27).

TABLE VIII

Oligonucleotide Series for Construction of
Translation Signals in M13IX22

	<u>Oligonucleotide</u>	<u>Sequence (5' to 3')</u>
5	015	AATT C GCC AAG GAG ACA GTC AT
	016	AATG AAA TAC CTA TTG CCT ACG GCA GCC GCT GGA TTG TT
	017	ATTA CTC GCT GCC CAA CCA GCC ATG GCC GAG CTC GTG AT
10	018	GACC CAG ACT CCA GATATC CAA CAG GAA TGA GTG TTA AT
	019	TCT AGA ACG CGT C
	020	ACGT G ACG CGT TCT AGA AT TAA CACTCA TTC CTG T
15	021	TG GAT ATC TGG AGT CTG GGT CAT CAC GAG CTC GGC CAT G
	022	GC TGG TTG GGC AGC GAG TAA TAA CAA TCC AGC GGC TGC C
	023	GT AGG CAA TAG GTA TTT CAT TAT
20		GAC TGT CCT TGG CG

Oligonucleotide 017 (SEQ ID NO: 27) contained a Sac I restriction site 67 nucleotides downstream from the ATG codon. The naturally occurring Eco RI site was removed and a new site introduced 25 nucleotides downstream from the Sac I. Oligonucleotides 5'-TGACTGTCTCCTTGGCGTGTGAAATTGTTA-3' (SEQ ID NO: 35) and 5'-TAACACTCATTCCGGATGGAATTCTGGAGTCTGGGT-3' (SEQ ID NO: 36) were used to generate each of the mutations, respectively. An amber stop codon was also introduced at position 3263 of M13mp18 using the oligonucleotide 5'-CAATTTTATCCTAAATCTTACCAAC-3' (SEQ ID NO: 37).

In addition to the above mutations, a variety of other modifications were made to remove certain sequences and redundant restriction sites. The LAC Z ribosome binding site was removed when the original Eco RI site in M13mp18 was mutated. Also, the Fok I sites at positions 239, 6361 and 7244 of M13mp18 were likewise removed with mutant oligonucleotides 5'-CATTTTGCAGATGGCTTAGA-3' (SEQ ID NO: 38), 5'-CGAAAGGGGGGTGTGCTGCAA-3' (SEQ ID NO: 39) and 5'-TAGCATTAACGTCCAATA-3' (SEQ ID NO: 40), respectively. Again, mutations within the coding region did not alter the amino acid sequence.

The resultant vector, M13IX22, is 7320 base pairs in length, the sequence of which is shown in Figure 6 (SEQ ID NO: 2). The Sac I and Eco RI cloning sites are at positions 6290 and 6314, respectively. Figure 3A also shows M13IX22 where each of the elements necessary for producing a surface expression library between right and left half randomized oligonucleotides is marked.

Library Construction

Each population of right and left half randomized oligonucleotides from columns 1R through 40R and columns 1L through 40L are cloned separately into M13IX42 and M13IX22, respectively, to create sublibraries of right and left half randomized oligonucleotides. Therefore, a total of eighty sublibraries are generated. Separately maintaining each population of randomized oligonucleotides until the final screening step is performed to ensure maximum efficiency of annealing of right and left half oligonucleotides. The greater efficiency increases the total number of randomized oligonucleotides which can be obtained. Alternatively, one can combine all forty populations of right half oligonucleotides (columns 1R-40R) into one population and

of left half oligonucleotides (columns 1L-40L) into a second population to generate just one sublibrary for each.

For the generation of sublibraries, each of the
 5 above populations of randomized oligonucleotides are cloned separately into the appropriate vector. The right half oligonucleotides are cloned into M13IX42 to generate sublibraries M13IX42.1R through M13IX42.40R. The left
 10 half oligonucleotides are similarly cloned into M13IX22 to generate sublibraries M13IX22.1L through M13IX22.40L. Each vector contains unique Eco RI and Sac I restriction enzyme sites which produce 5' and 3' single-stranded overhangs, respectively, when digested. The single
 15 strand overhangs are used for the annealing and ligation of the complementary single-stranded random oligonucleotides.

The randomized oligonucleotide populations are cloned between the Eco RI and Sac I sites by sequential digestion and ligation steps. Each vector is treated
 20 with an excess of Eco RI (New England Biolabs) at 37°C for 2 hours followed by addition of 4-24 units of calf intestinal alkaline phosphatase (Boehringer Mannheim, Indianapolis, IN). Reactions are stopped by phenol/chloroform extraction and ethanol precipitation.
 25 The pellets are resuspended in an appropriate amount of distilled or deionized water (dH₂O). About 10 pmol of vector is mixed with a 5000-fold molar excess of each population of randomized oligonucleotides in 10 µl of 1X ligase buffer (50 mM Tris-HCl, pH 7.8, 10 mM MgCl₂, 20 mM
 30 DTT, 1 mM ATP, 50 µg/ml BSA) containing 1.0 U of T4 DNA ligase (BRL, Gaithersburg, MD). The ligation is incubated at 16°C for 16 hours. Reactions are stopped by heating at 75°C for 15 minutes and the DNA is digested with an excess of Sac I (New England Biolabs) for 2

hours. Sac I is inactivated by heating at 75°C for 15 minutes and the volume of the reaction mixture is adjusted to 300 μ l with an appropriate amount of 10X ligase buffer and dH₂O. One unit of T4 DNA ligase (BRL) is added and the mixture is incubated overnight at 16°C. The DNA is ethanol precipitated and resuspended in TE (10 mM Tris-HCl, pH 8.0, 1 mM EDTA). DNA from each ligation is electroporated into XL1 BlueTM cells (Stratagene, La Jolla, CA), as described below, to generate the sublibraries.

E. coli XL1 BlueTM is electroporated as described by Smith et al., Focus 12:38-40 (1990) which is incorporated herein by reference. The cells are prepared by inoculating a fresh colony of XL1s into 5 mls of SOB without magnesium (20 g bacto-tryptone, 5 g bacto-yeast extract, 0.584 g NaCl, 0.186 g KCl, dH₂O to 1,000 mls) and grown with vigorous aeration overnight at 37°C. SOB without magnesium (500 ml) is inoculated at 1:1000 with the overnight culture and grown with vigorous aeration at 37°C until the OD₅₅₀ is 0.8 (about 2 to 3 h). The cells are harvested by centrifugation at 5,000 rpm (2,600 x g) in a GS3 rotor (Sorvall, Newtown, CT) at 4°C for 10 minutes, resuspended in 500 ml of ice-cold 10% (v/v) sterile glycerol and centrifuged and resuspended a second time in the same manner. After a third centrifugation, the cells are resuspended in 10% sterile glycerol at a final volume of about 2 ml, such that the OD₅₅₀ of the suspension is 200 to 300. Usually, resuspension is achieved in the 10% glycerol that remains in the bottle after pouring off the supernate. Cells are frozen in 40 μ l aliquots in microcentrifuge tubes using a dry ice-ethanol bath and stored frozen at -70°C.

Frozen cells are electroporated by thawing slowly on ice before use and mixing with about 10 pg to 500 ng of vector per 40 μ l of cell suspension. A 40 μ l aliquot is placed in an 0.1 cm electroporation chamber (Bio-Rad,
 5 Richmond, CA) and pulsed once at 0°C using 200 Ω parallel resistor, 25 μ F, 1.88 kV, which gives a pulse length (τ) of ~4 ms. A 10 μ l aliquot of the pulsed cells are diluted into 1 ml SOC (98 mls SOB plus 1 ml of 2 M $MgCl_2$ and 1 ml of 2 M glucose) in a 12- x 75-mm culture tube,
 10 and the culture is shaken at 37°C for 1 hour prior to culturing in selective media, (see below).

Each of the eighty sublibraries are cultured using methods known to one skilled in the art. Such methods can be found in Sanbrook et al., Molecular Cloning: A
 15 Laboratory Manual, Cold Spring Harbor Laboratory, Cold Spring Harbor, 1989, and in Ausubel et al., Current Protocols in Molecular Biology, John Wiley and Sons, New York, 1989, both of which are incorporated herein by reference. Briefly, the above 1 ml sublibrary cultures
 20 were grown up by diluting 50-fold into 2XYT media (16 g tryptone, 10 g yeast extract, 5 g NaCl) and culturing at 37°C for 5-8 hours. The bacteria were pelleted by centrifugation at 10,000 xg. The supernatant containing phage was transferred to a sterile tube and stored at
 25 4°C.

Double strand vector DNA containing right and left half randomized oligonucleotide inserts is isolated from the cell pellet of each sublibrary. Briefly, the pellet is washed in TE (10 mM Tris, pH 8.0, 1 mM EDTA) and
 30 recollected by centrifugation at 7,000 rpm for 5' in a Sorval centrifuge (Newtown, CT). Pellets are resuspended in 6 mls of 10% Sucrose, 50 mM Tris, pH 8.0. 3.0 ml of 10 mg/ μ l lysozyme is added and incubated on ice for 20 minutes. 12 mls of 0.2 M NaOH, 1% SDS is added followed

by 10 minutes on ice. The suspensions are then incubated on ice for 20 minutes after addition of 7.5 mls of 3 M NaOAc, pH 4.6. The samples are centrifuged at 15,000 rpm for 15 minutes at 4°C, RNased and extracted with
 5 phenol/chloroform, followed by ethanol precipitation. The pellets are resuspended, weighed and an equal weight of CsCl₂ is dissolved into each tube until a density of 1.60 g/ml is achieved. EtBr is added to 600 µg/ml and the double-stranded DNA is isolated by equilibrium
 10 centrifugation in a TV-1665 rotor (Sorval) at 50,000 rpm for 6 hours. These DNAs from each right and left half sublibrary are used to generate forty libraries in which the right and left halves of the randomized oligonucleotides have been randomly joined together.

15 Each of the forty libraries are produced by joining together one right half and one left half sublibrary. The two sublibraries joined together corresponded to the same column number for right and left half random oligonucleotide synthesis. For example, sublibrary
 20 M13IX42.1R is joined with M13IX22.1L to produce the surface expression library M13IX.1RL. In the alternative situation where only two sublibraries are generated from the combined populations of all right half synthesis and all left half synthesis, only one surface expression
 25 library would be produced.

For the random joining of each right and left half oligonucleotide populations into a single surface expression vector species, the DNAs isolated from each sublibrary are digested an excess of Fok I (New England
 30 Biolabs). The reactions are stopped by phenol/chloroform extraction, followed by ethanol precipitation. Pellets are resuspended in dH₂O. Each surface expression library is generated by ligating equal molar amounts (5-10 pmol) of Fok I digested DNA isolated from corresponding right

and left half sublibraries in 10 μ l of 1X ligase buffer containing 1.0 U of T4 DNA ligase (Bethesda Research Laboratories, Gaithersburg, MD). The ligations proceed overnight at 16°C and are electroporated into the sup O strain MK30-3 (Boehringer Mannheim Biochemical, (BMB), Indianapolis, IN) as previously described for XL1 cells. Because MK30-3 is sup O, only the vector portions encoding the randomized oligonucleotides which come together will produce viable phage.

10 Screening of Surface Expression Libraries

Purified phage are prepared from 50 ml liquid cultures of XL1 BlueTM cells (Stratagene) which are infected at a m.o.i. of 10 from the phage stocks stored at 4°C. The cultures are induced with 2 mM IPTG.

15 Supernatants from all cultures are combined and cleared by two centrifugations, and the phage are precipitated by adding 1/7.5 volumes of PEG solution (25% PEG-8000, 2.5 M NaCl), followed by incubation at 4°C overnight. The precipitate is recovered by centrifugation for 90 minutes

20 at 10,000 x g. Phage pellets are resuspended in 25 ml of 0.01 M Tris-HCl, pH 7.6, 1.0 mM EDTA, and 0.1% Sarkosyl and then shaken slowly at room temperature for 30 minutes. The solutions are adjusted to 0.5 M NaCl and to a final concentration of 5% polyethylene glycol. After 2

25 hours at 4°C, the precipitates containing the phage are recovered by centrifugation for 1 hour at 15,000 X g. The precipitates are resuspended in 10 ml of NET buffer (0.1 M NaCl, 1.0 mM EDTA, and 0.01 M Tris-HCl, pH 7.6), mixed well, and the phage repelleted by centrifugation at

30 170,000 X g for 3 hours. The phage pellets are subsequently resuspended overnight in 2 ml of NET buffer and subjected to cesium chloride centrifugation for 18 hours at 110,000 X g (3.86 g of cesium chloride in 10 ml of buffer). Phage bands are collected, diluted 7-fold

with NET buffer, recentrifuged at 170,000 X g for 3 hours, resuspended, and stored at 4°C in 0.3 ml of NET buffer containing 0.1 mM sodium azide.

- 5 Ligand binding proteins used for panning on streptavidin coated dishes are first biotinylated and then absorbed against UV-inactivated blocking phage (see below). The biotinylating reagents are dissolved in dimethylformamide at a ratio of 2.4 mg solid NHS-SS-
- 10 Biotin (sulfosuccinimidyl 2-(biotinamido)ethyl-1,3'-dithiopropionate; Pierce, Rockford, IL) to 1 ml solvent and used as recommended by the manufacturer. Small-scale reactions are accomplished by mixing 1 μ l dissolved
- 15 reagent with 43 μ l of 1 mg/ml ligand binding protein diluted in sterile bicarbonate buffer (0.1 M NaHCO₃, pH 8.6). After 2 hours at 25°C, residual biotinylating reagent is reacted with 500 μ l 1 M ethanolamine (pH adjusted to 9 with HCl) for an additional 2 hours. The entire sample is diluted with 1 ml TBS containing 1 mg/ml
- 20 BSA, concentrated to about 50 μ l on a Centricon 30 ultra-filter (Amicon), and washed on the same filter three times with 2 ml TBS and once with 1 ml TBS containing 0.02% NaN₃ and 7 x 10¹² UV-inactivated blocking phage (see below); the final retentate (60-80 μ l) is stored at 4°C.
- 25 Ligand binding proteins biotinylated with the NHS-SS-Biotin reagent are linked to biotin via a disulfide-containing chain.

- UV-irradiated M13 phage were used for blocking binding proteins which fortuitously bound filamentous
- 30 phage in general. M13mp8 (Messing and Vieira, Gene 19: 262-276 (1982), which is incorporated herein by reference) was chosen because it carries two amber stop codons, which ensure that the few phage surviving irradiation will not grow in the sup O strains used to
 - 35 titer the surface expression libraries. A 5 ml sample

containing 5×10^{13} M13mp8 phage, purified as described above, was placed in a small petri plate and irradiated with a germicidal lamp at a distance of two feet for 7 minutes (flux $150 \mu\text{W}/\text{cm}^2$). NaN_3 was added to 0.02% and
 5 phage particles concentrated to 10^{14} particles/ml on a Centricon 30-kDa ultrafilter (Amicon).

For panning, polystyrene petri plates (60 x 15 mm, Falcon; Becton Dickinson, Lincoln Park, NJ) are incubated with 1 ml of 1 mg/ml of streptavidin (BMB) in 0.1 M
 10 NaHCO_3 pH 8.6-0.02% NaN_3 in a small, air-tight plastic box overnight in a cold room. The next day streptavidin is removed and replaced with at least 10 ml blocking solution (29 mg/ml of BSA; 3 $\mu\text{g}/\text{ml}$ of streptavidin; 0.1 M NaHCO_3 pH 8.6-0.02% NaN_3) and incubated at least 1 hour at
 15 room temperature. The blocking solution is removed and plates are washed rapidly three times with Tris buffered saline containing 0.5% Tween 20 (TBS-0.5% Tween 20).

Selection of phage expressing peptides bound by the ligand binding proteins is performed with 5 μl (2.7 μg
 20 ligand binding protein) of blocked biotinylated ligand binding proteins reacted with a 50 μl portion of each library. Each mixture is incubated overnight at 4°C , diluted with 1 ml TBS-0.5% Tween 20, and transferred to a streptavidin-coated petri plate prepared as described
 25 above. After rocking 10 minutes at room temperature, unbound phage are removed and plates washed ten times with TBS-0.5% Tween 20 over a period of 30-90 minutes. Bound phage are eluted from plates with 800 μl sterile elution buffer (1 mg/ml BSA, 0.1 M HCl, pH adjusted to
 30 2.2 with glycerol) for 15 minutes and eluates neutralized with 48 μl 2 M Tris (pH unadjusted). A 20 μl portion of each eluate is titered on MK30-3 concentrated cells with dilutions of input phage.

A second round of panning is performed by treating 750 μ l of first eluate from each library with 5 mM DTT for 10 minutes to break disulfide bonds linking biotin groups to residual biotinylated binding proteins. The treated eluate is concentrated on a Centricon 30 ultrafilter (Amicon), washed three times with TBS-0.5% Tween 20, and concentrated to a final volume of about 50 μ l. Final retentate is transferred to a tube containing 5.0 μ l (2.7 μ g ligand binding protein) blocked biotinylated ligand binding proteins and incubated overnight. The solution is diluted with 1 ml TBS-0.5% Tween 20, panned, and eluted as described above on fresh streptavidin-coated petri plates. The entire second eluate (800 μ l) is neutralized with 48 μ l 2 M Tris, and 20 μ l is titered simultaneously with the first eluate and dilutions of the input phage.

Individual phage populations are purified through 2 to 3 rounds of plaque purification. Briefly, the second eluate titer plates are lifted with nitrocellulose filters (Schleicher & Schuell, Inc., Keene, NH) and processed by washing for 15 minutes in TBS (10 mM Tris-HCl, pH 7.2, 150 mM NaCl), followed by an incubation with shaking for an additional 1 hour at 37°C with TBS containing 5% nonfat dry milk (TBS-5% NDM) at 0.5 ml/cm². The wash is discarded and fresh TBS-5% NDM is added (0.1 ml/cm²) containing the ligand binding protein between 1 nM to 100 mM, preferably between 1 to 100 μ M. All incubations are carried out in heat-sealable pouches (Sears). Incubation with the ligand binding protein proceeds for 12-16 hours at 4°C with shaking. The filters are removed from the bags and washed 3 times for 30 minutes at room temperature with 150 mls of TBS containing 0.1% NDM and 0.2% NP-40 (Sigma, St. Louis, MO). The filters are then incubated for 2 hours at room temperature in antiserum against the ligand binding

protein at an appropriate dilution in TBS-0.5% NDM,
 washed in 3 changes of TBS containing 0.1% NDM and 0.2%
 NP-40 as described above and incubated in TBS containing
 0.1% NDM and 0.2% NP-40 with 1×10^6 cpm of ^{125}I -labeled
 5 Protein A (specific activity = 2.1×10^7 cpm/ μg). After
 a washing with TBS containing 0.1% NDM and 0.2% NP-40 as
 described above, the filters are wrapped in Saran Wrap
 and exposed to Kodak X-Omat x-ray film (Kodak, Rochester,
 NY) for 1-12 hours at -70°C using Dupont Cronex Lightning
 10 Plus Intensifying Screens (Dupont, Willmington, DE).

Positive plaques identified are cored with the large
 end of a pasteur pipet and placed into 1 ml of SM (5.8 g
 NaCl, 2 g $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, 50 ml 1 M Tris-HCl, pH 7.5, 5 mls 2%
 gelatin, to 1000 mls with dH_2O) plus 1-3 drops of CHCl_3
 15 and incubated at 37°C 2-3 hours or overnight at 4°C . The
 phage are diluted 1:500 in SM and 2 μl are added to 300
 μl of XL1 cells plus 3 mls of soft agar per 100 mm^2
 plate. The XL1 cells are prepared for plating by growing
 a colony overnight in 10 ml LB (10 g bacto-tryptone, 5 g
 20 bacto-yeast extract, 10 g NaCl, 1000 ml dH_2O) containing
 100 μl of 20% maltose and 100 μl of 1 M MgSO_4 . The
 bacteria are pelleted by centrifugation at 2000 $\times g$ for
 10 minutes and the pellet is resuspended gently in 10 mls
 of 10 mM MgSO_4 . The suspension is diluted 4-fold by
 25 adding 30 mls of 10 mM MgSO_4 to give an OD_{600} of
 approximately 0.5. The second and third round screens
 are identical to that described above except that the
 plaques are cored with the small end of a pasteur pipet
 and placed into 0.5 mls SM plus a drop of CHCl_3 and 1-5
 30 μl of the phage following incubation are used for plating
 without dilution. At the end of the third round of
 purification, an individual plaque is picked and the
 templates prepared for sequencing.

Template Preparation and Sequencing

Templates are prepared for sequencing by inoculating a 1 ml culture of 2XYT containing a 1:100 dilution of an overnight culture of XL1 with an individual plaque. The
5 plaques are picked using a sterile toothpick. The culture is incubated at 37°C for 5-6 hours with shaking and then transferred to a 1.5 ml microfuge tube. 200 μ l of PEG solution is added, followed by vortexing and placed on ice for 10 minutes. The phage precipitate is
10 recovered by centrifugation in a microfuge at 12,000 x g for 5 minutes. The supernatant is discarded and the pellet is resuspended in 230 μ l of TE (10 mM Tris-HCl, pH 7.5, 1 mM EDTA) by gently pipeting with a yellow pipet tip. Phenol (200 μ l) is added, followed by a brief
15 vortex and microfuged to separate the phases. The aqueous phase is transferred to a separate tube and extracted with 200 μ l of phenol/chloroform (1:1) as described above for the phenol extraction. A 0.1 volume of 3 M NaOAc is added, followed by addition of 2.5
20 volumes of ethanol and precipitated at -20°C for 20 minutes. The precipitated templates are recovered by centrifugation in a microfuge at 12,000 x g for 8 minutes. The pellet is washed in 70% ethanol, dried and resuspended in 25 μ l TE. Sequencing was performed using
25 a SequenaseTM sequencing kit following the protocol supplied by the manufacturer (U.S. Biochemical, Cleveland, OH).

EXAMPLE II

Isolation and Characterization of Peptide Ligands
Generated from Oligonucleotides Having Random Codons at Two
Predetermined Positions

5 This example shows the generation of a surface
 expression library from a population of oligonucleotides
 having randomized codons. The oligonucleotides are ten
 codons in length and are cloned into a single vector
 species for the generation of a M13 gene VIII-based
 10 surface expression library. The example also shows the
 selection of peptides for a ligand binding protein and
 characterization of their encoded nucleic acid sequences.

Oligonucleotide Synthesis

15 Oligonucleotides were synthesized as described in
 Example I. The synthesizer was programmed to synthesize
 the sequences shown in Table IX. These sequences
 correspond to the first random codon position synthesized
 and 3' flanking sequences of the oligonucleotide which
 hybridizes to the leader sequence in the vector. The
 20 complementary sequences are used for insertional
 mutagenesis of the synthesized population of
 oligonucleotides.

Table IX

	<u>Column</u>	<u>Sequence (5' to 3')</u>
25	column 1	AA (A/C) GGTTGGTCGGTACCGG
	column 2	AG (A/G) GGTTGGTCGGTACCGG
	column 3	AT (A/G) GGTTGGTCGGTACCGG
	column 4	AC (A/G) GGTTGGTCGGTACCGG
	column 5	CA (G/T) GGTTGGTCGGTACCGG
30	column 6	CT (G/C) GGTTGGTCGGTACCGG

column 7	AG (T/C) GGTTGGTCGGTACCGG
column 8	AT (T/C) GGTTGGTCGGTACCGG
column 9	CC (A/C) GGTTGGTCGGTACCGG
column 10	T (A/T) TGGTTGGTCGGTACCGG

5 The next eight random codon positions were
synthesized as described for Table V in Example I.
Following the ninth position synthesis, the reaction
products were once more combined, mixed and redistributed
into 10 new reaction columns. Synthesis of the last
10 random codon position and 5' flanking sequences are shown
in Table X.

Table X

	<u>Column</u>	<u>Sequence (5' to 3')</u>
	column 1	AGGATCCGCCGAGCTCAA (A/C) <u>A</u>
15	column 2	AGGATCCGCCGAGCTCAG (A/G) <u>A</u>
	column 3	AGGATCCGCCGAGCTCAT (A/G) <u>A</u>
	column 4	AGGATCCGCCGAGCTCAC (A/G) <u>A</u>
	column 5	AGGATCCGCCGAGCTCCA (G/T) <u>A</u>
	column 6	AGGATCCGCCGAGCTCCT (G/C) <u>A</u>
20	column 7	AGGATCCGCCGAGCTCAG (T/C) <u>A</u>
	column 8	AGGATCCGCCGAGCTCAT (T/C) <u>A</u>
	column 9	AGGATCCGCCGAGCTCCC (A/C) <u>A</u>
	column 10	AGGATCCGCCGAGCTCT (A/T) <u>TA</u>

25 The reaction products were mixed once more and the
oligonucleotides cleaved and purified as recommended by
the manufacturer. The purified population of
oligonucleotides were used to generate a surface
expression library as described below.

Vector Construction

The vector used for generating surface expression libraries from a single oligonucleotide population (i.e., without joining together of right and left half

5 oligonucleotides) is described below. The vector is a M13-based expression vector which directs the synthesis of gene VIII-peptide fusion proteins (Figure 4). This vector exhibits all the functions that the combined right and left half vectors of Example I exhibit.

10 An M13-based vector was constructed for the cloning and surface expression of populations of random oligonucleotides (Figure 4, M13IX30), M13mp19 (Pharmacia) was the starting vector. This vector was modified to contain, in addition to the encoded wild type M13 gene

15 VIII: (1) a pseudo-wild type gene, gene VIII sequence with an amber stop codon placed between it and the restriction sites for cloning oligonucleotides; (2) Stu I, Spe I and Xho I restriction sites in frame with the pseudo-wild type gVIII for cloning oligonucleotides; (3)

20 sequences necessary for expression, such as a promoter, signal sequence and translation initiation signals; (4) various other mutations to remove redundant restriction sites and the amino terminal portion of Lac Z.

Construction of M13IX30 was performed in four steps.

25 In the first step, a precursor vector containing the pseudo gene VIII and various other mutations was constructed, M13IX01F. The second step involved the construction of a small cloning site in a separate M13mp18 vector to yield M13IX03. In the third step,

30 expression sequences and cloning sites were constructed in M13IX03 to generate the intermediate vector M13IX04B. The fourth step involved the incorporation of the newly constructed sequences from the intermediate vector into

M13IX01F to yield M13IX30. Incorporation of these sequences linked them with the pseudo gene VIII.

Construction of the precursor vector M13IX01F was similar to that of M13IX42 described in Example I except
 5 for the following features: (1) M13mp19 was used as the starting vector; (2) the Fok I site 5' to the unique Eco RI site was not incorporated and the overhang at the naturally occurring Fok I site at position 3547 was not
 10 changed to 5'-CTTC-3'; (3) the spacer sequence was not incorporated between the Eco RI and Sac I sites; and (4) the amber codon at position 4492 was not incorporated.

In the second step, M13mp18 was mutated to remove the 5' end of Lac Z up to the Lac i binding site and including the Lac Z ribosome binding site and start
 15 codon. Additionally, the polylinker was removed and a Mlu I site was introduced in the coding region of Lac Z. A single oligonucleotide was used for these mutagenesis and had the sequence "5'-
 AAACGACGGCCAGTGCCAAGTGACGCGTGTGAAATTGTTATCC-3'" (SEQ ID
 20 NO: 41). Restriction enzyme sites for Hind III and Eco RI were introduced downstream of the MluI site using the oligonucleotide "5'-
 GGCGAAAGGGAATTCTGCAAGGCGATTAAGCTTGGGTAACGCC-3'" (SEQ ID
 NO: 42). These modifications of M13mp18 yielded the
 25 vector M13IX03.

The expression sequences and cloning sites were introduced into M13IX03 by chemically synthesizing a series of oligonucleotides which encode both strands of the desired sequence. The oligonucleotides are presented
 30 in Table XI (SEQ ID NOS: 43 through 50).

TABLE XI
M13IX30 Oligonucleotide Series

<u>Top Strand</u> <u>Oligonucleotides</u>		<u>Sequence (5' to 3')</u>
5	084	GGCGTTACCCAAGCTTTGTACATGGAGAAAATAAAG
	027	TGAAACAAAGCACTATTGCACTGGCACTCTTACCGT TACCGT
	028	TACTGTTTACCCCTGTGACAAAAGCCGCCCAGGTCC AGCTGC
10	029	TCGAGTCAGGCCTATTGTGCCCAGGGATTGTACTAG TGGATCCG
<u>Bottom</u> <u>Oligonucleotides</u>		<u>Sequence (5' to 3')</u>
15	085	TGGCGAAAGGGAATTCGGATCCACTAGTACAATCCCTG
	031	GGCACAATAGGCCTGACTCGAGCAGCTGGACCAGGGCG GCTT
20	032	TTGTCACAGGGGTAAACAGTAACGGTAACGGTAAGTGT GCCA
	033	GTGCAATAGTGCTTTGTTTCACTTTATTTTCTCCATGT ACAA
25	The above oligonucleotides except for the terminal	
	oligonucleotides 084 (SEQ ID NO: 43) and 085 (SEQ ID NO:	
	47) of Table XI were mixed, phosphorylated, annealed and	
	ligated to form a double stranded insert as described in	
	Example I. However, instead of cloning directly into the	
30	intermediate vector the insert was first amplified by PCR	
	using the terminal oligonucleotides 084 (SEQ ID NO: 43)	
	and 085 (SEQ ID NO: 47) as primers. The terminal	
	oligonucleotide 084 (SEQ ID NO: 43) contains a Hind III	
	site 10 nucleotides internal to its 5' end.	

Oligonucleotide 085 (SEQ ID NO: 47) has an Eco RI site at its 5' end. Following amplification, the products were restricted with Hind III and Eco RI and ligated as described in Example I into the polylinker of M13mp18
 5 digested with the same two enzymes. The resultant double stranded insert contained a ribosome binding site, a translation initiation codon followed by a leader sequence and three restriction enzyme sites for cloning random oligonucleotides (Xho I, Stu I, Spe I). The
 10 vector was named M13IX04.

During cloning of the double-stranded insert, it was found that one of the GCC codons in oligonucleotides 028 and its complement in 031 was deleted. Since this deletion did not affect function, the final construct is
 15 missing one of the two GCC codons. Additionally, oligonucleotide 032 contained a GTG codon where a GAG codon was needed. Mutagenesis was performed using the oligonucleotide 5'-TAACGGTAAGAGTGCCAGTGC-3' (SEQ ID NO: 51) to convert the codon to the desired sequence. The
 20 resultant intermediate vector was named M13IX04B.

The fourth step in constructing M13IX30 involved inserting the expression and cloning sequences from M13IX04B upstream of the pseudo-wild type gVIII in M13IX01F. This was accomplished by digesting M13IX04B
 25 with Dra III and Ban HI and gel isolating the 700 base pair insert containing the sequences of interest. M13IX01F was likewise digested with Dra III and Bam HI. The insert was combined with the double digested vector at a molar ratio of 3:1 and ligated as described in
 30 Example I. It should be noted that all modifications in the vectors described herein were confirmed by sequence analysis. The sequence of the final construct, M13IX30, is shown in Figure 7 (SEQ ID NO: 3). Figure 4 also shows

M13IX30 where each of the elements necessary for surface expression of randomized oligonucleotides is marked.

Library Construction, Screening and Characterization of Encoded Oligonucleotides

5 Construction of an M13IX30 surface expression library is accomplished identically to that described in Example I for sublibrary construction except the oligonucleotides described above are inserted into M13IX30 by mutagenesis instead of by ligation. The library is constructed and propagated on MK30-3 (BMB) and phage stocks are prepared for infection of XLI cells and screening. The surface expression library is screened and encoding oligonucleotides characterized as described in Example I.

15 EXAMPLE III

Isolation and Characterization of Peptide Ligands Generated from Right and Left Half Degenerate Oligonucleotides

20 This example shows the construction and expression of a surface expression library of degenerate oligonucleotides. The encoded peptides of this example derive from the mixing and joining together of two separate oligonucleotide populations. Also demonstrated is the isolation and characterization of peptide ligands and their corresponding nucleotide sequence for specific binding proteins.

25

Synthesis of Oligonucleotide Populations

A population of left half degenerate oligonucleotides and a population of right half degenerate oligonucleotides was synthesized using
 5 standard automated procedures as described in Example I.

The degenerate codon sequences for each population of oligonucleotides were generated by sequentially synthesizing the triplet NNG/T where N is an equal mixture of all four nucleotides. The antisense sequence
 10 for each population of oligonucleotides was synthesized and each population contained 5' and 3' flanking sequences complementary to the vector sequence. The complementary termini was used to incorporate each population of oligonucleotides into their respective
 15 vectors by standard mutagenesis procedures. Such procedures have been described previously in Example I and in the Detailed Description. Synthesis of the antisense sequence of each population was necessary since the single-stranded form of the vectors are obtained only
 20 as the sense strand.

The left half oligonucleotide population was synthesized having the following sequence: 5'-
 AGCTCCCGGATGCCTCAGAAGATG(A/CNN)₉GGCTTTTGCCACAGGGG-3' (SEQ
 ID NO: 52). The right half oligonucleotide population
 25 was synthesized having the following sequence: 5'-
 CAGCCTCGGATCCGCC(A/CNN)₁₀ATG(A/C)GAAT-3' (SEQ ID NO. 53).
 These two oligonucleotide populations when incorporated into their respective vectors and joined together encode
 a 20 codon oligonucleotide having 19 degenerate positions
 30 and an internal predetermined codon sequence.

Vector Construction

Modified forms of the previously described vectors were used for the construction of right and left half sublibraries. The construction of left half sublibraries was performed in an M13-based vector termed M13ED03. This vector is a modified form of the previously described M13IX30 vector and contains all the essential features of both M13IX30 and M13IX22. M13ED03 contains, in addition to a wild type and a pseudo-wild type gene VIII, sequences necessary for expression and two Fok I sites for joining with a right half oligonucleotide sublibrary. Therefore, this vector combines the advantages of both previous vectors in that it can be used for the generation and expression of surface expression libraries from a single oligonucleotide population or it can be joined with a sublibrary to bring together right and left half oligonucleotide populations into a surface expression library.

M13ED03 was constructed in two steps from M13IX30. The first step involved the modification of M13IX30 to remove a redundant sequence and to incorporate a sequence encoding the eight amino-terminal residues of human β -endorphin. The leader sequence was also mutated to increase secretion of the product.

During construction of M13IX04 (an intermediate vector to M13IX30 which is described in Example II), a six nucleotide sequence was duplicated in oligonucleotide 027 (SEQ ID NO: 44) and its complement 032 (SEQ ID NO: 49). This sequence, 5'-TTACCG-3', was deleted by mutagenesis in the construction of M13ED01. The oligonucleotide used for the mutagenesis was 5'-GGTAAACAGTAACGGTAAGAGTGCCAG-3' (SEQ ID NO: 54). The mutation in the leader sequence was generated using the

oligonucleotide 5'-GGGCTTTTGCCACAGGGGT-3' (SEQ ID NO: 55). This mutagenesis resulted in the A residue at position 6353 of M13IX30 being changed to a G residue. The resultant vector was designated M13IX32.

5 To generate M13ED01, the nucleotide sequence encoding β -endorphin (8 amino acid residues of β -endorphin plus 3 extra amino acid residues) was incorporated after the leader sequence by mutagenesis. The oligonucleotide used had the following sequence: 5'-
 10 AGGGTCATCGCCTTCAGCTCCGGATCCCTCAGAAGTCATAAACCCCCCATAGGC
 TTTTGCCAC-3' (SEQ ID NO: 56). This mutagenesis also removed some of the downstream sequences through the Spe I site.

The second step in the construction of M13ED03
 15 involved vector changes which put the β -endorphin sequence in frame with the downstream pseudo-gene VIII sequence and incorporated a Fok I site for joining with a sublibrary of right half oligonucleotides. This vector was designed to incorporate oligonucleotide populations
 20 by mutagenesis using sequences complementary to those flanking or overlapping with the encoded β -endorphin sequence. The absence of β -endorphin expression after mutagenesis can therefore be used to measure the mutagenesis frequency. In addition to the above vector
 25 changes, M13ED03 was also modified to contain an amber codon at position 3262 for biological selection during joining of right and left half sublibraries.

The mutations were incorporated using standard mutagenesis procedures as described in Example I. The
 30 frame shift changes and Fok I site were generated using the oligonucleotide 5'-
 TCGCCTTCAGCTCCCGGATGCCTCAGAAGCATGAACCCCCCATAGGC-3' (SEQ ID NO: 57). The amber codon was generated using the

oligonucleotide 5'-CAATTTTATCCTAAATCTTACCAAC-3' (SEQ ID NO: 58). The full sequence of the resultant vector, M13ED03, is provided in Figure 8 (SEQ ID NO: 4).

The construction of right half oligonucleotide
 5 sublibraries was performed in a modified form of the M13IX42 vector. The new vector, M13IX421, is identical to M13IX42 except that the amber codon between the Eco RI-SacI cloning site and the pseudo-gene VIII sequence was removed. This change ensures that all expression off
 10 of the Lac Z promoter produces a peptide-gene VIII fusion protein. Removal of the amber codon was performed by mutagenesis using the following oligonucleotide: 5'-GCCTTCAGCCTCGGATCCGCC-3' (SEQ ID NO: 59). The full sequence of M13IX421 is shown in Figure 9 (SEQ ID NO: 5).

15 Library Construction, Screening and Characterization of Encoded Oligonucleotides

A sublibrary was constructed for each of the previously described degenerate populations of oligonucleotides. The left half population of
 20 oligonucleotides was incorporated into M13ED03 to generate the sublibrary M13ED03.L and the right half population of oligonucleotides was incorporated into M13IX421 to generate the sublibrary M13IX421.R. Each of the oligonucleotide populations were incorporated into
 25 their respective vectors using site-directed mutagenesis as described in Example I. Briefly, the nucleotide sequences flanking the degenerate codon sequences were complementary to the vector at the site of incorporation. The populations of nucleotides were hybridized to single-
 30 stranded M13ED03 or M13IX421 vectors and extended with T4 DNA polymerase to generate a double-stranded circular vector. Mutant templates were obtained by uridine selection in vivo, as described by Kunkel et al., supra.

Each of the vector populations were electroporated into host cells and propagated as described in Example I.

The random joining of right and left half sublibraries into a single surface expression library was accomplished as described in Example I except that prior to digesting each vector population with Fok I they were first digested with an enzyme that cuts in the unwanted portion of each vector. Briefly, M13ED03.L was digested with Bgl II (cuts at 7094) and M13IX421.R was digested with Hind III (cuts at 3919). Each of the digested populations were further treated with alkaline phosphatase to ensure that the ends would not religate and then digested with an excess of Fok I. Ligations, electroporation and propagation of the resultant library was performed as described in Example I.

The surface expression library was screened for ligand binding proteins using a modified panning procedure. Briefly, 1 ml of the library, about 10^{12} phage particles, was added to 1-5 μ g of the ligand binding protein. The ligand binding protein was either an antibody or receptor globulin (Rg) molecule, Aruffo et al., Cell 61:1303-1313 (1990), which is incorporated herein by reference. Phage were incubated shaking with affinity ligand at room temperature for 1 to 3 hours followed by the addition of 200 μ l of latex beads (Biosite, San Diego, CA) which were coated with goat-antimouse IgG. This mixture was incubated shaking for an additional 1-2 hours at room temperature. Beads were pelleted for 2 minutes by centrifugation in a microfuge and washed with TBS which can contain 0.1% Tween 20. Three additional washes were performed where the last wash did not contain any Tween 20. The bound phage were then eluted with 200 μ l 0.1 M Glycine-HCl, pH 2.2 for 15 minutes and the beads were spun down by centrifugation.

The supernatant-containing phage (eluate) was removed and phage exhibiting binding to the ligand binding protein were further enriched by one-to-two more cycles of panning. Typical yields after the first eluate were
 5 about 1×10^6 - 5×10^6 pfu. The second and third eluate generally yielded about 5×10^6 - 2×10^7 pfu and 5×10^7 - 1×10^{10} pfu, respectively.

The second or third eluate was plated at a suitable density for plaque identification screening and
 10 sequencing of positive clones (i.e., plated at confluency for rare clones and 200-500 plaques/plate if pure plaques were needed). Briefly, plaques grown for about 6 hours at 37°C and were overlaid with nitrocellulose filters that had been soaked in 2 mM IPTG and then briefly dried.
 15 The filters remained on the plaques overnight at room temperature, removed and placed in blocking solution for 1-2 hours. Following blocking, the filters were incubated in $1 \mu\text{g/ml}$ ligand binding protein in blocking solution for 1-2 hours at room temperature. Goat
 20 antimouse Ig-coupled alkaline phosphatase (Fisher) was added at a 1:1000 dilution and the filters were rapidly washed with 10 mls of TBS or block solution over a glass vacuum filter. Positive plaques were identified after alkaline phosphatase development for detection.

25 Screening of the degenerate oligonucleotide library with several different ligand binding proteins resulted in the identification of peptide sequences which bound to each of the ligands. For example, screening with an antibody to β -endorphin resulted in the detection of
 30 about 30-40 different clones which essentially all had the core amino acid sequence known to interact with the antibody. The sequences flanking the core sequences were different showing that they were independently derived and not duplicates of the same clone. Screening with an

antibody known as 57 gave similar results (i.e., a core consensus sequence was identified but the flanking sequences among the clones were different).

EXAMPLE IV

5 Generation of a Left Half Random Oligonucleotide Library

This example shows the synthesis and construction of a left half random oligonucleotide library.

A population of random oligonucleotides nine codons in length was synthesized as described in Example I
10 except that different sequences at their 5' and 3' ends were synthesized so that they could be easily inserted into the vector by mutagenesis. Also, the mixing and dividing steps for generating random distributions of reaction products was performed by the alternative method
15 of dispensing equal volumes of bead suspensions. The liquid chosen that was dense enough for the beads to remain dispersed was 100% acetonitrile.

Briefly, each column was prepared for the first coupling reaction by suspending 22 mg (1 μ mole) of 48
20 μ mol/g capacity beads (Genta, San Diego, CA) in 0.5 mls of 100% acetonitrile. These beads are smaller than those described in Example I and are derivatized with a guanine nucleotide. They also do not have a controlled pore size. The bead suspension was then transferred to an
25 empty reaction column. Suspensions were kept relatively dispersed by gently pipetting the suspension during transfer. Columns were plugged and monomer coupling reactions were performed as shown in Table XII.

Table XII

	<u>Column</u>	<u>Sequence</u> <u>(5' to 3')</u>
	column 1L	AA (A/C) GGCTTTTGCCACAGG
5	column 2L	AG (A/G) GGCTTTTGCCACAGG
	column 3L	AT (A/G) GGCTTTTGCCACAGG
	column 4L	AC (A/G) GGCTTTTGCCACAGG
	column 5L	CA (G/T) GGCTTTTGCCACAGG
	column 6L	CT (G/C) GGCTTTTGCCACAGG
10	column 7L	AG (T/C) GGCTTTTGCCACAGG
	column 8L	AT (T/C) GGCTTTTGCCACAGG
	column 9L	CC (A/C) GGCTTTTGCCACAGG
	column 10L	T (A/T) TGGCTTTTGCCACAGG

After coupling of the last monomer, the columns were unplugged as described previously and their contents were poured into a 1.5 ml microfuge tube. The columns were rinsed with 100% acetonitrile to recover any remaining beads. The volume used for rinsing was determined so that the final volume of total bead suspension was about 100 μ l for each new reaction column that the beads would be aliquoted into. The mixture was vortexed gently to produce a uniformly dispersed suspension and then divided, with constant pipetting of the mixture, into equal volumes. Each mixture of beads was then transferred to an empty reaction column. The empty tubes were washed with a small volume of 100% acetonitrile and also transferred to their respective columns. Random codon positions 2 through 9 were then synthesized as described in Example I where the mixing and dividing steps were performed using a suspension in 100% acetonitrile. The coupling reactions for codon positions 2 through 9 are shown in Table XIII.

Table XIII

	<u>Column</u>	<u>Sequence</u> (5' to 3')
5	column 1L	AA(A/C) <u>A</u>
	column 2L	AG(A/G) <u>A</u>
	column 3L	AT(A/G) <u>A</u>
	column 4L	AC(A/G) <u>A</u>
	column 5L	CA(G/T) <u>A</u>
10	column 6L	CT(G/C) <u>A</u>
	column 7L	AG(T/C) <u>A</u>
	column 8L	AT(T/C) <u>A</u>
	column 9L	CC(A/C) <u>A</u>
	column 10L	T(A/T) <u>TA</u>

After coupling of the last monomer for the ninth
 15 codon position, the reaction products were mixed and a
 portion was transferred to an empty reaction column.
 Columns were plugged and the following monomer coupling
 reactions were performed: 5'-CGGATGCCTCAGAAGCCCCXXA-3'
 (SEQ ID NO: 60). The resulting population of random
 20 oligonucleotides was purified and incorporated by
 mutagenesis into the left half vector M13ED04.

M13ED04 is a modified version of the M13ED03 vector
 described in Example III and therefore contains all the
 features of that vector. The difference between M13ED03
 25 and M13ED04 is that M13ED04 does not contain the five
 amino acid sequence (Tyr Gly Gly Phe Met) recognized by
 anti- β -endorphin antibody. This sequence was deleted by
 mutagenesis using the oligonucleotide 5'-
 CGGATGCCTCAGAAGGGCTTTTGCCACAGG (SEQ ID NO: 61). The
 30 entire nucleotide sequence of this vector is shown in
 Figure 10 (SEQ ID NO: 6).

Although the invention has been described with reference to the presently preferred embodiment, it should be understood that various modifications can be made without departing from the spirit of the invention.

5 Accordingly, the invention is limited only by the claims.

10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
200
205
210
215
220
225
230
235
240
245
250
255
260
265
270
275
280
285
290
295
300
305
310
315
320
325
330
335
340
345
350
355
360
365
370
375
380
385
390
395
400
405
410
415
420
425
430
435
440
445
450
455
460
465
470
475
480
485
490
495
500
505
510
515
520
525
530
535
540
545
550
555
560
565
570
575
580
585
590
595
600
605
610
615
620
625
630
635
640
645
650
655
660
665
670
675
680
685
690
695
700
705
710
715
720
725
730
735
740
745
750
755
760
765
770
775
780
785
790
795
800
805
810
815
820
825
830
835
840
845
850
855
860
865
870
875
880
885
890
895
900
905
910
915
920
925
930
935
940
945
950
955
960
965
970
975
980
985
990
995

SEQUENCE LISTING

(1) GENERAL INFORMATION:

- (i) APPLICANT: Huse, William D.
- (ii) TITLE OF INVENTION: SURFACE EXPRESSION LIBRARIES OF
RANDOMIZED PEPTIDES
- (iii) NUMBER OF SEQUENCES: 61
- (iv) CORRESPONDENCE ADDRESS:
 - (A) ADDRESSEE: Pretty, Schroeder, Brueggemann & Clark
 - (B) STREET: 444 South Flower Street, Suite 2000
 - (C) CITY: Los Angeles
 - (D) STATE: California
 - (E) COUNTRY: United States
 - (F) ZIP: 90071
- (v) COMPUTER READABLE FORM:
 - (A) MEDIUM TYPE: Floppy disk
 - (B) COMPUTER: IBM PC compatible
 - (C) OPERATING SYSTEM: PC-DOS/MS-DOS
 - (D) SOFTWARE: PatentIn Release #1.0, Version #1.25
- (vi) CURRENT APPLICATION DATA:
 - (A) APPLICATION NUMBER:
 - (B) FILING DATE:
 - (C) CLASSIFICATION:
- (viii) ATTORNEY/AGENT INFORMATION:
 - (A) NAME: Campbell, Cathryn A
 - (B) REGISTRATION NUMBER: 31,815
 - (C) REFERENCE/DOCKET NUMBER: P31 9072
- (ix) TELECOMMUNICATION INFORMATION:
 - (A) TELEPHONE: (619) 535-9001
 - (B) TELEFAX: (619) 535-8949

(2) INFORMATION FOR SEQ ID NO:1:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 7294 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: both
 - (D) TOPOLOGY: circular

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

AATGCTACTA CTATTAGTAG AATTGATGCC ACCTTTTCAG CTCGCGCCCC AAATGAAAAT	60
ATAGCTAAAC AGGTTATTGA CCATTGCGA AATGTATCTA ATGGTCAAAC TAAATCTACT	120
CGTTCGAGA ATTGGGAATC AACTGTTACA TGGAATGAAA CTTCCAGACA CCGTACTTTA	180

GTTGCATATT TAAAACATGT TGAGCTACAG CACCAGATTC AGCAATTAAG CTCTAAGCCA	240
TCTGCAAAAA TGACCTCTTA TCAAAAGGAG CAATTAAAGG TACTCTCTAA TCCTGACCTG	300
TTGGAGTTTG CTTCCGGTCT GGTTCGCTTT GAAGCTCGAA TTAAACGCG ATATTTGAAG	360
TCTTTCGGGC TTCCTCTTAA TCTTTTTGAT GCAATCCGCT TTGCTTCTGA CTATAATAGT	420
CAGGGTAAAG ACCTGATTTT TGATTTATGG TCATTCTCGT TTTCTGAACT GTTTAAAGCA	480
TTTGAGGGGG ATTCAATGAA TATTTATGAC GATTCCGCAG TATTGGACGC TATCCAGTCT	540
AAACATTTTA CTATTACCCC CTCTGGCAA ACTTCTTTTG CAAAAGCCTC TCGCTATTTT	600
GGTTTTTATC GTCGTCTGGT AAACGAGGGT TATGATAGTG TTGCTCTTAC TATGCCTCGT	660
AATTCCTTTT GCGGTTATGT ATCTGCATTA GTTGAATGTG GTATTCCTAA ATCTCAACTG	720
ATGAATCTTT CTACCTGTAA TAATGTTGTT CCGTTAGTTC GTTTTATTAA CGTAGATTTT	780
TCTTCCCAAC GTCCTGACTG GTATAATGAG CCAGTTCTTA AAATCGCATA AGGTAATTCA	840
CAATGATTAA AGTTGAAATT AAACCATCTC AAGCCCAATT TACTACTCGT TCTGGTGTTT	900
CTCGTCAGGG CAAGCCTTAT TCACTGAATG AGCAGCTTTG TTACGTTGAT TTGGGTAATG	960
AATATCCGGT TCTTGTCAAG ATTACTCTTG ATGAAGGTCA GCCAGCCTAT GCGCCTGGTC	1020
TGTACACCGT TCATCTGTCC TCTTTCAAAG TTGGTCAGTT CGGTTCCCTT ATGATTGACC	1080
GTCTGCGCCT CGTTCCGGCT AAGTAACATG GAGCAGGTCG CGGATTTCGA CACAATTTAT	1140
CAGGCGATGA TACAAATCTC CGTTGTACTT TGTTTCGCGC TTGGTATAAT CGCTGGGGGT	1200
CAAAGATGAG TGTTTTAGTG TATTCTTTCG CCTCTTTCGT TTTAGGTTGG TGCCTTCGTA	1260
GTGGCATTAC GTATTTTACC CGTTTAATGG AAACCTCCTC ATGAAAAAGT CTTTAGTCCT	1320
CAAAGCCTCT GTAGCCGTTG CTACCCTCGT TCCGATGCTG TCTTTCGCTG CTGAGGGTGA	1380
CGATCCCGCA AAAGCGGCCT TTAACCTCCT GCAAGCCTCA GCGACCGAAT ATATCGGTTA	1440
TGCGTGGGCG ATGGTTGTTG TCATTGTCGG CGCAACTATC GGTATCAAGC TGTTTAAGAA	1500
ATTCACCTCG AAAGCAAGCT GATAAACCGA TACAATTAAA GGCTCCTTTT GGAGCCTTTT	1560
TTTTTGAGGA TTTTCAACGT GAAAAATTA TTATTCGCAA TTCCTTTAGT TGTTCTTTTC	1620
TATTCTCACT CCGCTGAAAC TGTTGAAAGT TGTTTAGCAA AACCCCATAC AGAAAATTCA	1680
TTTACTAACG TCTGGAAAGA CGACAAAAC TTAGATCGTT ACGCTAACTA TGAGGGTTGT	1740
CTGTGGAATG CTACAGGCGT TGTAGTTTGT ACTGGTGACG AAACCTCAGTG TTACGGTACA	1800
TGGGTTCCTA TTGGGCTTGC TATCCCTGAA AATGAGGGTG GTGGCTCTGA GGGTGGCGGT	1860
TCTGAGGGTG GCGGTTCTGA GGGTGGCGGT ACTAAACCTC CTGAGTACGG TGATACACCT	1920
ATTCCGGGCT ATACTTATAT CAACCCTCTC GACGGCACTT ATCCGCCTGG TACTGAGCAA	1980

AACCCCGCTA ATCCTAATCC TTCTCTTGAG GAGTCTCAGC CTCTTAATAC TTTCATGTTT	2040
CAGAAATAATA GGTTCGAAA TAGGCAGGGG GCATTAAGTG TTTATACGGG CACTGTTACT	2100
CAAGGCACTG ACCCCGTTAA AACTTATTAC CAGTACACTC CTGTATCATC AAAAGCCATG	2160
TATGACGCTT ACTGGAACGG TAAATTCAGA GACTGCGCTT TCCATTCTGG CTTTAATGAA	2220
GATCCATTCG TTTGTGAATA TCAAGGCCAA TCGTCTGACC TGCCTCAACC TCCTGTCAAT	2280
GCTGGCGGCG GCTCTGGTGG TGGTTCTGGT GCGGCTCTG AGGGTGGTGG CTCTGAGGGT	2340
GGCGGTTCTG AGGGTGGCGG CTCTGAGGGA GCGGTTCCG GTGGTGGCTC TGGTCCGGT	2400
GATTTTGATT ATGAAAAGAT GGCAAACGCT AATAAGGGGG CTATGACCGA AAATGCCGAT	2460
GAAAACGCGC TACAGTCTGA CGCTAAAGGC AACTTGATT CTGTCGCTAC TGATTACGGT	2520
GCTGCTATCG ATGGTTTCAT TGGTGACGTT TCCGGCCTTG CTAATGGTAA TGGTGCTACT	2580
GGTGATTTTG CTGGCTCTAA TTCCCAAATG GCTCAAGTCG GTGACGGTGA TAATTCACCT	2640
TTAATGAATA ATTTCCGTCA ATATTACCT TCCCTCCCTC AATCGGTTGA ATGTCGCCCT	2700
TTTGTCTTTA GCGCTGGTAA ACCATATGAA TTTTCTATTG ATTGTGACAA AATAAACTTA	2760
TTCCGTGGTG TCTTTGCGTT TCTTTTATAT GTTGCCACCT TTATGTATGT ATTTTCTACG	2820
TTTGCTAACA TACTGCGTAA TAAGGAGTCT TAATCATGCC AGTTCTTTTG GGTATTCCGT	2880
TATTATTGCG TTTCTCGGT TTCTTCTGG TAACTTTGTT CGGCTATCTG CTTACTTTTC	2940
TTAAAAAGGG CTTCGGTAAG ATAGCTATTG CTATTTCAAT GTTTCTTGCT CTTATTATTG	3000
GGCTTAACTC AATTCTTG TGTTATCTCT CTGATATTAG CGCTCAATTA CCCTCTGACT	3060
TTGTTACAGG TGTTCAAGTT ATTTCTCCGT CTAATGCGCT TCCCTGTTTT TATGTTATTC	3120
TCTCTGTAAA GGCTGCTATT TTCATTTTTG ACGTTAAACA AAAAATCGTT TCTTATTTGG	3180
ATTGGGATAA ATAATATGGC TGTTTATTTT GTAACGGCA AATTAGGCTC TGGAAAGACG	3240
CTCGTTAGCG TTGGTAAGAT TCAGGATAAA ATTGTAGCTG GGTGCAAAAT AGCAACTAAT	3300
CTTGATTTAA GGCTTCAAAA CCTCCCGCAA GTCGGGAGGT TCGCTAAAAC GCCTCGCGTT	3360
CTTAGAATAC CGGATAAGCC TTCTATATCT GATTGCTTG CTATTGGGCG CGGTAATGAT	3420
TCCTACGATG AAAATAAAAA CGGCTTGCTT GTTCTCGATG AGTGCGGTAC TTGGTTTAAT	3480
ACCCGTTCTT GGAATGATAA GGAAAGACAG CCGATTATTG ATTGGTTTCT ACATGCTCGT	3540
AAATTAGGAT GGGATATTAT CTTCTTGTT CAGGACTTAT CTATTGTTGA TAAACAGGCG	3600
CGTTCGTCAT TAGCTGAACA TGTTGTTTAT TGTCGTCGTC TGGACAGAAT TACTTTACCT	3660
TTTGTGCGTA CTTTATATTC TCTTATTACT GGCTCGAAAA TGCCTCTGCC TAAATTACAT	3720
GTTGGCGTTG TTAAATATGG CGATTCTCAA TTAAGCCCTA CTGTTGAGCG TTGGCTTTAT	3780

ACTGGTAAGA ATTTGTATAA CGCATATGAT ACTAAACAGG CTTTTTCTAG TAATTATGAT	3840
TCCGGTGTTT ATTCTTATTT AACGCCTTAT TTATCACACG GTCGGTATTT CAAACCATTA	3900
AATTTAGGTC AGAAGATGAA GCTTACTAAA ATATATTTGA AAAAGTTTTT CACGCGTTCTT	3960
TGTCTTGCGA TTGGATTTGC ATCAGCATTT ACATATAGTT ATATAACCCA ACCTAAGCCG	4020
GAGGTTAAAA AGGTAGTCTC TCAGACCTAT GATTTTGATA AATTCATAT TGACTCTTCT	4080
CAGCGTCTTA ATCTAAGCTA TCGCTATGTT TTCAAGGATT CTAAGGGAAA ATTAATTAAT	4140
AGCGACGATT TACAGAAGCA AGGTTATTCA CTCACATATA TTGATTTATG TACTGTTTCC	4200
ATTAAAAAGG TAATTCAAAT GAAATTGTTA AATGTAATTA ATTTTGTTTT CTTGATGTTT	4260
GTTTCATCAT CTTCTTTTGC TCAGGTAATT GAAATGAATA ATTTCGCCTCT GCGCGATTTT	4320
GTAAGTTGGT ATTCAAAGCA ATCAGGCGAA TCCGTTATTG TTTCTCCCGA TGTAAGAGGT	4380
ACTGTTACTG TATATTCATC TGACGTTAAA CCTGAAAATC TACGCAATTT CTTTATTTCT	4440
GTTTTACGTG CTAATAATTT TGATATGGTT GGTCAATTC CTTCCATTAT TTAGAAGTAT	4500
AATCCAAACA ATCAGGATTA TATTGATGAA TTGCCATCAT CTGATAATCA GGAATATGAT	4560
GATAATTCCG CTCCTTCTGG TGGTTTCTTT GTTCCGCAAA ATGATAATGT TACTCAAAC	4620
TTTAAATTA ATAACGTTTC GGCAAAGGAT TTAATACGAG TTGTCGAATT GTTTGTAAG	4680
TCTAATACTT CTAAATCCTC AAATGTATTA TCTATTGACG GCTCTAATCT ATTAGTTGTT	4740
AGTGACCTA AAGATATTTT AGATAACCTT CCTCAATTCC TTTCTACTGT TGATTTGCCA	4800
ACTGACCAGA TATTGATTGA GGGTTTGATA TTTGAGGTTT AGCAAGGTGA TGCTTTAGAT	4860
TTTTCATTTG CTGCTGGCTC TCAGCGTGGC ACTGTTGCAG GCGGTGTTAA TACTGACCGC	4920
CTCACCTCTG TTTTATCTTC TGCTGGTGGT TCGTTCCGTA TTTTAAATGG CGATGTTTTA	4980
GGGCTATCAG TTCGCGCATT AAAGACTAAT AGCCATTCAA AAATATTGTC TGTGCCACGT	5040
ATTCTTACGC TTTCAGGTCA GAAGGGTTCT ATCTCTGTTG GCCAGAATGT CCCTTTTATT	5100
ACTGGTCGTG TGAAGTGGTA ATCTGCCAAT GTAAATAATC CATTTTCAGAC GATTGAGCGT	5160
CAAAATGTAG GTATTTCCAT GAGCGTTTTT CCTGTTGCAA TGGCTGGCGG TAATATTGTT	5220
CTGGATATTA CCAGCAAGGC CGATAGTTTG AGTTCTTCTA CTCAGGCAAG TGATGTTATT	5280
ACTAATCAAA GAAGTATTGC TACAACGGTT AATTTGCGTG ATGGACAGAC TCTTTTACTC	5340
GGTGGCCTCA CTGATTATAA AAACACTTCT CAAGATTCTG GCGTACCGTT CCTGTCTAAA	5400
ATCCCTTTAA TCGGCCTCCT GTTTAGCTCC CGCTCTGATT CCAACGAGGA AAGCACGTTA	5460
TACGTGCTCG TCAAAGCAAC CATAGTACGC GCCCTGTAGC GGCGCATTA GCGCGGCGGG	5520
TGTGGTGGTT ACGCGCAGCG TGACCGCTAC ACTTGCCAGC GCCCTAGCGC CCGCTCCTTT	5580

CGCTTTCTTC	CCTTCCTTTC	TCGCCACGTT	CGCCGGCTTT	CCCCGTCAAG	CTCTAAATCG	5640
GGGGCTCCCT	TTAGGGTTCC	GATTTAGTGC	TTTACGGCAC	CTCGACCCCA	AAAAACTTGA	5700
TTTGGGTGAT	GGTTCACGTA	GTGGGCCATC	GCCCTGATAG	ACGGTTTTTC	GCCCTTTGAC	5760
GTTGGAGTCC	ACGTTCTTTA	ATAGTGGACT	CTTGTTCCAA	ACTGGAACAA	CACTCAACCC	5820
TATCTCGGGC	TATTCTTTTG	ATTTATAAGG	GATTTTGCCG	ATTTCTGGAAC	CACCATCAAA	5880
CAGGATTTTC	GCCTGCTGGG	GCAAACCAGC	GTGGACCGCT	TGCTGCAACT	CTCTCAGGGC	5940
CAGGCGGTGA	AGGGCAATCA	GCTGTTGCCC	GTCTCGCTGG	TGAAAAGAAA	AACCACCCTG	6000
GCGCCCAATA	CGCAAACCGC	CTCTCCCCGC	GCGTTGGCCG	ATTCATTAAT	GCAGCTGGCA	6060
CGACAGGTTT	CCCGACTGGA	AAGCGGGCAG	TGAGCGCAAC	GCAATTAATG	TGAGTTAGCT	6120
CACTCATTAG	GCACCCAGG	CTTTACACTT	TATGCTTCCG	GCTCGTATGT	TGTGTGGAAT	6180
TGTGAGCGGA	TAACAATTTT	ACACAGGAAA	CAGCTATGAC	CAGGATGTAC	GAATTCGCAG	6240
GTAGGAGAGC	TCGGCGGATC	CTAGGCTGAA	GGCGATGACC	CTGCTAAGGC	TGCATTCAAT	6300
AGTTTACAGG	CAAGTGCTAC	TGAGTACATT	GGCTACGCTT	GGGCTATGGT	AGTAGTTATA	6360
GTTGGTGCTA	CCATAGGGAT	TAAATTATTC	AAAAAGTTTA	CGAGCAAGGC	TTCTTAACCA	6420
GCTGGCGTAA	TAGCGAAGAG	GCCCCGACCG	ATCGCCCTTC	CCAACAGTTG	CGCAGCCTGA	6480
ATGGCGAATG	GCGCTTTGCC	TGGTTTCCGG	CACCAGAAGC	GGTGCCGGAA	AGCTGGCTGG	6540
AGTGCGATCT	TCCTGAGGCC	GATACGGTCG	TCGTCCCCTC	AACTGGCAG	ATGCACGGTT	6600
ACGATGCGCC	CATCTACACC	AACGTAACCT	ATCCCATTAC	GGTCAATCCG	CCGTTTGTTT	6660
CCACGGAGAA	TCCGACGGGT	TGTTACTCGC	TCACATTTAA	TGTTGATGAA	AGCTGGCTAC	6720
AGGAAGGCCA	GACGCGAATT	ATTTTTGATG	GCGTTCCTAT	TGGTTAAAAA	ATGAGCTGAT	6780
TTAACAAAAA	TTTAACGCGA	ATTTTAACAA	AATATTAACG	TTTACAATTT	AAATATTTGC	6840
TTATACAATC	TTCTGTTTTT	TGGGGCTTTT	CTGATTATCA	ACCGGGGTAC	ATATGATTGA	6900
CATGCTAGTT	TTACGATTAC	CGTTCATCGA	TTCTCTTGTT	TGCTCCAGAC	TCTCAGGCAA	6960
TGACCTGATA	GCCTTTGTAG	ATCTCTCAAA	AATAGCTACC	CTCTCCGGCA	TTAATTTATC	7020
AGCTAGAACG	GTTGAATATC	ATATTGATGG	TGATTTGACT	GTCTCCGGCC	TTTCTCACCC	7080
TTTTGAATCT	TTACCTACAC	ATTACTCAGG	CATTGCATTT	AAAATATATG	AGGGTTCTAA	7140
AAATTTTTTAT	CCTTGCGTTG	AAATAAAGGC	TTCTCCCGCA	AAAGTATTAC	AGGGTCATAA	7200
TGTTTTTGGT	ACAACCGATT	TAGCTTTATG	CTCTGAGGCT	TTATTGCTTA	ATTTTGCTAA	7260
TTCTTTGCCT	TGCCTGTATG	ATTTATTGGA	CGTT			7294

(2) INFORMATION FOR SEQ ID NO:2:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 7320 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: both
- (D) TOPOLOGY: circular

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

AATGCTACTA CTATTAGTAG AATTGATGCC ACCTTTTCAG CTCGCGCCCC AAATGAAAAT	60
ATAGCTAAAC AGGTTATTGA CCATTTGCGA AATGTATCTA ATGGTCAAAC TAAATCTACT	120
CGTTCGCAGA ATTGGGAATC AACTGTTACA TGGAATGAAA CTTCCAGACA CCGTACTTTA	180
GTTGCATATT TAAAACATGT TGAGCTACAG CACCAGATTC AGCAATTAAG CTCTAAGCCA	240
TCTGCAAAAA TGACCTCTTA TCAAAAGGAG CAATTAAAGG TACTCTCTAA TCCTGACCTG	300
TTGGAGTTTG CTTCCGGTCT GGTTCGCTTT GAAGCTCGAA TTAAAACGCG ATATTTGAAG	360
TCTTTCGGGC TTCCTCTTAA TCTTTTTGAT GCAATCCGCT TTGCTTCTGA CTATAATAGT	420
CAGGGTAAAG ACCTGATTTT TGATTTATGG TCATTCTCGT TTTCTGAACT GTTTAAAGCA	480
TTTGAGGGGG ATTCAATGAA TATTTATGAC GATTCCGCAG TATTGGACGC TATCCAGTCT	540
AAACATTTTA CTATTACCCC CTCTGGCAAA ACTTCTTTTG CAAAAGCCTC TCGCTATTTT	600
GGTTTTTATC GTCGTCTGGT AAACGAGGGT TATGATAGTG TTGCTCTTAC TATGCCTCGT	660
AATTCCTTTT GGC GTTATGT ATCTGCATTA GTTGAATGTG GTATTCCTAA ATCTCAACTG	720
ATGAATCTTT CTACCTGTAA TAATGTTGTT CCGTTAGTTC GTTTTATTAA CGTAGATTTT	780
TCTTCCCAAC GTCCTGACTG GTATAATGAG CCAGTTCTTA AAATCGCATA AGGTAATTCA	840
CAATGATTAA AGTTGAAATT AAACCATCTC AAGCCCAATT TACTACTCGT TCTGGTGTTT	900
CTCGTCAGGG CAAGCCTTAT TCACTGAATG AGCAGCTTTG TTACGTTGAT TTGGGTAATG	960
AATATCCGGT TCTTGTCAAG ATTACTCTTG ATGAAGGTCA GCCAGCCTAT GCGCCTGGTC	1020
TGTACACCGT TCATCTGTCC TCTTTCAAAG TTGGTCAGTT CGGTTCCCTT ATGATTGACC	1080
GTCTGCGCCT CGTTCCGGCT AAGTAACATG GAGCAGGTG CGGATTTCTGA CACAATTTAT	1140
CAGGCGATGA TACAAATCTC CGTTGTACTT TGTTTCGCGC TTGGTATAAT CGCTGGGGGT	1200
CAAAGATGAG TGTTTTAGTG TATTCTTTTCG CCTCTTTTCGT TTTAGGTTGG TGCCTTCGTA	1260
GTGGCATTAC GTATTTTACC CGTTTAATGG AAACCTCCTC ATGAAAAAGT CTTTAGTCCT	1320
CAAAGCCTCT GTAGCCGTTG CTACCCTCGT TCCGATGCTG TCTTTCGCTG CTGAGGGTGA	1380
CGATCCCGCA AAAGCGGCCT TTAACCTCCT GCAAGCCTCA GCGACCGAAT ATATCGGTTA	1440

TGCGTGGGCG	ATGGTTGTTG	TCATTGTCGG	CGCAACTATC	GGTATCAAGC	TGTTTAAGAA	1500
ATTCACCTCG	AAAGCAAGCT	GATAAACCGA	TACAATTAAA	GGCTCCTTTT	GGAGCCTTTT	1560
TTTTTGGAGA	TTTTCACGT	GAAAAAATTA	TTATTCGCAA	TTCTTTTAGT	TGTTCCCTTTC	1620
TATTCTCACT	CCGCTGAAAC	TGTTGAAAGT	TGTTTAGCAA	AACCCCATAC	AGAAAATTCA	1680
TTTACTAACG	TCTGGAAAGA	CGACAAAACT	TTAGATCGTT	ACGCTAACTA	TGAGGGTTGT	1740
CTGTGGAATG	CTACAGGCGT	TGTAGTTTGT	ACTGGTGACG	AAACTCAGTG	TTACGGTACA	1800
TGGGTTCCCTA	TTGGGCTTGC	TATCCCTGAA	AATGAGGGTG	GTGGCTCTGA	GGGTGGCGGT	1860
TCTGAGGGTG	GCGGTTCTGA	GGGTGGCGGT	ACTAAACCTC	CTGAGTACGG	TGATACACCT	1920
ATTCCGGGCT	ATACTTATAT	CAACCCTCTC	GACGGCACTT	ATCCGCCTGG	TACTGAGCAA	1980
AACCCCGCTA	ATCCTAATCC	TTCTCTTGAG	GAGTCTCAGC	CTCTTAATAC	TTTCATGTTT	2040
CAGAATAATA	GGTTCGAAA	TAGGCAGGGG	GCATTAACTG	TTTATACGGG	CACTGTTACT	2100
CAAGGCACTG	ACCCCGTTAA	AACTTATTAC	CAGTACACTC	CTGTATCATC	AAAAGCCATG	2160
TATGACGCTT	ACTGGAACGG	TAAATTCAGA	GACTGCGCTT	TCCATTCTGG	CTTTAATGAA	2220
GATCCATTCTG	TTTGTGAATA	TCAAGGCCAA	TCGTCTGACC	TGCCTCAACC	TCCTGTCAAT	2280
GCTGGCGGCG	GCTCTGGTGG	TGGTTCCTGGT	GGCGGCTCTG	AGGGTGGTGG	CTCTGAGGGT	2340
GGCGGTTCTG	AGGGTGGCGG	CTCTGAGGGA	GGCGGTTCCG	GTGGTGGCTC	TGGTTCGGGT	2400
GATTTTGATT	ATGAAAAGAT	GGCAAACGCT	AATAAGGGGG	CTATGACCGA	AAATGCCGAT	2460
GAAAACGCGC	TACAGTCTGA	CGCTAAAGGC	AACTTGATT	CTGTCGCTAC	TGATTACGGT	2520
GCTGCTATCG	ATGGTTTCAT	TGGTGACGTT	TCCGGCCTTG	CTAATGGTAA	TGGTGCTACT	2580
GGTGATTTTG	CTGGCTCTAA	TTCCCAAATG	GCTCAAGTCG	GTGACGGTGA	TAATTCACCT	2640
TTAATGAATA	ATTTCCGTCA	ATATTTACCT	TCCCTCCCTC	AATCGGTTGA	ATGTCGCCCT	2700
TTTGTCTTTA	GCGCTGGTAA	ACCATATGAA	TTTTCTATTG	ATTGTGACAA	AATAAACTTA	2760
TTCCGTGGTG	TCTTTGCGTT	TCTTTTATAT	GTTGCCACCT	TTATGTATGT	ATTTTCTACG	2820
TTTGCTAACA	TACTGCGTAA	TAAGGAGTCT	TAATCATGCC	AGTTCTTTTG	GGTATTCGGT	2880
TATTATTGCG	TTTCCTCGGT	TTCCTTCTGG	TAACTTTGTT	CGGCTATCTG	CTTACTTTTC	2940
TTAAAAAGGG	CTTCGGTAAG	ATAGCTATTG	CTATTTCAAT	GTTTCTTGCT	CTTATTATTG	3000
GGCTTAACTC	AATTCTTG TG	GGTTATCTCT	CTGATATTAG	CGCTCAATTA	CCCTCTGACT	3060
TTGTTCAGGG	TGTTCAGTTA	ATTCTCCCGT	CTAATGCGCT	TCCCTGTTTT	TATGTTATTC	3120
TCTCTGTAAA	GGCTGCTATT	TTCATTTTTG	ACGTTAAACA	AAAAATCGTT	TCTTATTTGG	3180
ATTGGGATAA	ATAATATGGC	TGTTTATTTT	GTAAGTGGCA	AATTAGGCTC	TGGAAAGACG	3240

CTCGTTAGCG	TTGGTAAGAT	TTAGGATAAA	ATTGTAGCTG	GGTGCAAAAT	AGCAACTAAT	3300
CTTGATTTAA	GGCTTCAAAA	CCTCCCGCAA	GTCGGGAGGT	TCGCTAAAAC	GCCTCGCGTT	3360
CTTAGAATAC	CGGATAAGCC	TTCTATATCT	GATTTGCTTG	CTATTGGGCG	CGGTAATGAT	3420
TCCTACGATG	AAAATAAAAA	CGGCTTGCTT	GTTCTCGATG	AGTGCGGTAC	TTGGTTTAAT	3480
ACCCGTTCTT	GGAATGATAA	GGAAAGACAG	CCGATTATTG	ATTGGTTTCT	ACATGCTCGT	3540
AAATTAGGAT	GGGATATTAT	CTTCCTTGTT	CAGGACTTAT	CTATTGTTGA	TAAACAGGCG	3600
CGTTCTGCAT	TAGCTGAACA	TGTTGTTTAT	TGTCGTCGTC	TGGACAGAAT	TACTTTACCT	3660
TTTGTCGGTA	CTTTATATTC	TCTTATTACT	GGCTCGAAAA	TGCCTCTGCC	TAAATTACAT	3720
GTTGGCGTTG	TTAAATATGG	CGATTCTCAA	TTAAGCCCTA	CTGTTGAGCG	TTGGCTTTAT	3780
ACTGGTAAGA	ATTTGTATAA	CGCATATGAT	ACTAAACAGG	CTTTTTCTAG	TAATTATGAT	3840
TCCGGTGTTT	ATTCTTATTT	AACGCCTTAT	TTATCACACG	GTCGGTATTT	CAAACCATTA	3900
AATTTAGGTC	AGAAGATGAA	ATTAActAAA	ATATATTTGA	AAAAGTTTTC	TCGCGTTCCT	3960
TGTCTTGCGA	TTGGATTTGC	ATCAGCATTT	ACATATAGTT	ATATAACCCA	ACCTAAGCCG	4020
GAGGTTAAAA	AGGTAGTCTC	TCAGACCTAT	GATTTTGATA	AATTCACTAT	TGACTCTTCT	4080
CAGCGTCTTA	ATCTAAGCTA	TCGCTATGTT	TTCAAGGATT	CTAAGGGAAA	ATTAATTAAT	4140
AGCGACGATT	TACAGAAGCA	AGGTTATTCA	CTCACATATA	TTGATTTATG	TACTGTTTCC	4200
ATTAAAAAAG	GTAATTCAAA	TGAAATTGTT	AAATGTAATT	AATTTTGTTT	TCTTGATGTT	4260
TGTTTCATCA	TCTTCTTTTG	CTCAGGTAAT	TGAAATGAAT	AATTCGCCTC	TGCGCGATTT	4320
TGTAACTTGG	TATTCAAAGC	AATCAGGCGA	ATCCGTTATT	GTTTCTCCCG	ATGTAAAAGG	4380
TACTGTTACT	GTATATTCAT	CTGACGTTAA	ACCTGAAAAT	CTACGCAATT	TCTTTATTTT	4440
TGTTTTACGT	GCTAATAATT	TTGATATGGT	TGTTTCAATT	CCTTCCATAA	TTCAGAAGTA	4500
TAATCCAAAC	AATCAGGATT	ATATTGATGA	ATTGCCATCA	TCTGATAATC	AGGAATATGA	4560
TGATAATTCC	GCTCCTTCTG	GTGGTTTCTT	TGTTCCGCAA	AATGATAATG	TTACTCAAAC	4620
TTTTAAAAATT	AATAACGTTC	GGGCAAAGGA	TTTAATACGA	GTTGTCGAAT	TGTTTGTAAG	4680
GTCTAATACT	TCTAAATCCT	CAAATGTATT	ATCTATTGAC	GGCTCTAATC	TATTAGTTGT	4740
TAGTGCACCT	AAAGATATTT	TAGATAACCT	TCCTCAATTC	CTTTCTACTG	TTGATTTGCC	4800
AACTGACCAG	ATATTGATTG	AGGGTTTGAT	ATTTGAGGTT	CAGCAAGGTG	ATGCTTTAGA	4860
TTTTTCATTT	GCTGCTGGCT	CTCAGCGTGG	CACTGTTGCA	GGCGGTGTTA	ATACTGACCG	4920
CCTCACCTCT	GTTTTATCTT	CTGCTGGTGG	TTCGTTGCGT	ATTTTTAATG	GCGATGTTTT	4980
AGGGCTATCA	GTTGCGCGAT	TAAAGACTAA	TAGCCATTCA	AAAATATTGT	CTGTGCCACG	5040

TATTCTTACG CTTTCAGGTC AGAAGGGTTC TATCTCTGTT GGCCAGAATG TCCCTTTTAT	5100
TACTGGTCGT GTGACTGGTG AATCTGCCAA TGTAATAAAT CCATTTCAGA CGATTGAGCG	5160
TCAAAATGTA GGTATTTCCA TGAGCGTTTT TCCTGTTGCA ATGGCTGGCG GTAATATTGT	5220
TCTGGATATT ACCAGCAAGG CCGATAGTTT GAGTTCTTCT ACTCAGGCAA GTGATGTTAT	5280
TACTAATCAA AGAAGTATTG CTACAACGGT TAATTTGCGT GATGGACAGA CTCTTTTACT	5340
CGGTGGCCTC ACTGATTATA AAAACACTTC TCAAGATTCT GGCCTACCGT TCCTGTCTAA	5400
AATCCCTTTA ATCGGCCTCC TGTTTAGCTC CCGCTCTGAT TCCAACGAGG AAAGCACGTT	5460
ATACGTGCTC GTCAAAGCAA CCATAGTACG CGCCCTGTAG CGGCGCATT AAGCGGGCGG	5520
GTGTGGTGGT TACGCGCAGC GTGACCGCTA CACTTGCCAG CGCCCTAGCG CCCGCTCCTT	5580
TCGCTTTCTT CCCTTCCTTT CTCGCCACGT TCGCCGGCTT TCCCCGTCAA GCTCTAAATC	5640
GGGGGCTCCC TTTAGGGTTC CGATTTAGTG CTTTACGGCA CCTCGACCCC AAAAACTTG	5700
ATTTGGGTGA TGGTTCACGT AGTGGGCCAT CGCCCTGATA GACGGTTTTT CGCCCTTTGA	5760
CGTTGGAGTC CACGTTCTTT AATAGTGGAC TCTTGTCCA AACTGGAACA AACTCAACC	5820
CTATCTCGGG CTATTCTTTT GATTTATAAG GGATTTTGCC GATTTTCGGAA CCACCATCAA	5880
ACAGGATTTT CGCCTGCTGG GGCAAACCAG CGTGGACCGC TTGCTGCAAC TCTCTCAGGG	5940
CCAGGCGGTG AAGGGCAATC AGCTGTTGCC CGTCTCGCTG GTGAAAAGAA AAACCACCCT	6000
GGCGCCCAAT ACGCAAACCG CCTCTCCCCG CGCGTTGGCC GATTCATTAA TGCAGCTGGC	6060
ACGACAGGTT TCCCGACTGG AAAGCGGGCA GTGAGCGCAA CGCAATTAAT GTGAGTTAGC	6120
TCACTCATT AAGCAACCCAG GCTTTACACT TTATGCTTCC GGCTCGTATG TTGTGTGGAA	6180
TTGTGAGCGG ATAACAATTT CACACGCCAA GGAGACAGTC ATAATGAAAT ACCTATTGCC	6240
TACGGCAGCC GCTGGATTGT TATTACTCGC TGCCCAACCA GCCATGGCCG AGCTCGTGAT	6300
GACCCAGACT CCAGAATTCC ATCCGGAATG AGTGTTAATT CTAGAACCGG TAAGCTTGGC	6360
ACTGGCCGTC GTTTTACAAC GTCGTGACTG GGAAAACCCT GGCGTTACCC AACTTAATCG	6420
CCTTGCAGCA CACCCCCCTT TCGCCAGCTG GCGTAATAGC GAAGAGGCCG GCACCGATCG	6480
CCCTTCCCAA CAGTTGCGCA GCCTGAATGG CGAATGGCGC TTTGCCTGGT TTCCGGCACC	6540
AGAAGCGGTG CCGGAAAGCT GGCTGGAGTG CGATCTTCCT GAGGCCGATA CGGTCGTCGT	6600
CCCCTCAAAC TGGCAGATGC ACGGTTACGA TCGCCCATC TACACCAACG TAACCTATCC	6660
CATTACGGTC AATCCGCCGT TTGTTCCAC GGAGAATCCG ACGGGTTGTT ACTCGCTCAC	6720
ATTTAATGTT GATGAAAGCT GGCTACAGGA AGGCCAGACG CGAATTATTT TTGATGGCGT	6780
TCCTATTGGT TAAAAATGA GCTGATTTAA CAAAAATTA ACGCGAATTT TAACAAAATA	6840

TTAACGTTTA CAATTTAAAT ATTTGCTTAT ACAATCTTCC TGTTTTTGGG GCTTTTCTGA	6900
TTATCAACCG GGGTACATAT GATTGACATG CTAGTTTAC GATTACCGTT CATCGATTCT	6960
CTTGTTTGCT CCAGACTCTC AGGCAATGAC CTGATAGCCT TTGTAGATCT CTCAAAAATA	7020
GCTACCCTCT CCGGCATTAA TTTATCAGCT AGAACGGTTG AATATCATAT TGATGGTGAT	7080
TTGACTGTCT CCGGCCTTTC TCACCCTTTT GAATCTTTAC CTACACATTA CTCAGGCATT	7140
GCATTTAAAA TATATGAGGG TTCTAAAAAT TTTTATCCTT GCGTTGAAAT AAAGGCTTCT	7200
CCCGCAAAAG TATTACAGGG TCATAATGTT TTTGGTACAA CCGATTTAGC TTTATGCTCT	7260
GAGGCTTTAT TGCTTAATTT TGCTAATTCT TTGCCTTGCC TGTATGATTT ATTGGACGTT	7320

(2) INFORMATION FOR SEQ ID NO:3:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 7445 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: both
- (D) TOPOLOGY: circular

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:3:

AATGCTACTA CTATTAGTAG AATTGATGCC ACCTTTTCAG CTCGCGCCCC AAATGAAAAAT	60
ATAGCTAAAC AGGTTATTGA CCATTTGCGA AATGTATCTA ATGGTCAAAC TAAATCTACT	120
CGTTGCGAGA ATTGGGAATC AACTGTTACA TGGAATGAAA CTTCCAGACA CCGTACTTTA	180
GTTGCATATT TAAAACATGT TGAGCTACAG CACCAGATTC AGCAATTAAG CTCTAAGCCA	240
TCTGCAAAAA TGACCTCTTA TCAAAAGGAG CAATTAAAGG TACTCTCTAA TCCTGACCTG	300
TTGGAGTTTG CTTCCGGTCT GGTTCGCTTT GAAGCTCGAA TTAAAACGCG ATATTTGAAG	360
TCTTTCGGGC TTCCTCTTAA TCTTTTTGAT GCAATCCGCT TTGCTTCTGA CTATAATAGT	420
CAGGGTAAAG ACCTGATTTT TGATTTATGG TCATTCTCGT TTTCTGAACT GTTTAAAGCA	480
TTTGAGGGGG ATTCAATGAA TATTTATGAC GATTCCGCAG TATTGGACGC TATCCAGTCT	540
AAACATTTTA CTATTACCCC CTCTGGCAAA ACTTCTTTTG CAAAAGCCTC TCGCTATTTT	600
GGTTTTTATC GTCGTCTGGT AAACGAGGGT TATGATAGTG TTGCTCTTAC TATGCCTCGT	660
AATTCCTTTT GCGTTATGT ATCTGCATTA GTTGAATGTG GTATTCCTAA ATCTCAACTG	720
ATGAATCTTT CTACCTGTAA TAATGTTGTT CCGTTAGTTC GTTTTATTAA CGTAGATTTT	780
TCTTCCCAAC GTCCTGACTG GTATAATGAG CCAGTTCTTA AAATCGCATA AGGTAATTCA	840
CAATGATTAA AGTTGAAATT AAACCATCTC AAGCCCAATT TACTACTCGT TCTGGTGTTT	900
CTCGTCAGGG CAAGCCTTAT TCACTGAATG AGCAGCTTTG TTACGTTGAT TTGGGTAATG	960

AATATCCGGT TCTTGTC AAG ATTACTCTTG ATGAAGGTCA GCCAGCCTAT GCGCCTGGTC	1020
TGTACACCGT TCATCTGTCC TCTTTCAAAG TTGGTCAGTT CGGTTCCCTT ATGATTGACC	1080
GTCTGCGCCT CGTTCCGGCT AAGTAACATG GAGCAGGTCTG CGGATTTCGA CACAATTTAT	1140
CAGGCGATGA TACAAATCTC CGTTGTACTT TGTTTTCGCGC TTGGTATAAT CGCTGGGGGT	1200
CAAAGATGAG TGTTTTAGTG TATTCTTTTCG CCTCTTTTCGT TTTAGGTTGG TGCCTTCGTA	1260
GTGGCATTAC GTATTTTACC CGTTTAATGG AAACCTTCCTC ATGAAAAAGT CTTTAGTCCT	1320
CAAAGCCTCT GTAGCCGTTG CTACCCTCGT TCCGATGCTG TCTTTCGCTG CTGAGGGTGA	1380
CGATCCCGCA AAAGCGGCCT TTAACCTCCCT GCAAGCCTCA GCGACCGAAT ATATCGGTTA	1440
TGCGTGGGCG ATGGTTGTTG TCATTGTCTG CGCAACTATC GGTATCAAGC TGTTTAAGAA	1500
ATTCACCTCG AAAGCAAGCT GATAAACC GA TACAATTAAA GGCTCCTTTT GGAGCCTTTT	1560
TTTTTGAGAGA TTTTCAACGT GAAAAAATTA TTATTCGCAA TTCCTTTAGT TGTTCCCTTC	1620
TATTCTCACT CCGCTGAAAC TGTGAAAGT TGTTTAGCAA AACCCCATAC AGAAAATTCA	1680
TTTACTAACG TCTGGAAAGA CGACAAAAC TTAGATCGTT ACGCTAACTA TGAGGGTTGT	1740
CTGTGGAATG CTACAGGCGT TGTAGTTTGT ACTGGTGACG AAACCTCAGTG TTACGGTACA	1800
TGGGTTCCCTA TTGGGCTTGC TATCCCTGAA AATGAGGGTG GTGGCTCTGA GGGTGGCGGT	1860
TCTGAGGGTG GCGGTTCTGA GGGTGGCGGT ACTAAACCTC CTGAGTACGG TGATACACCT	1920
ATTCCGGGCT ATACTTATAT CAACCCTCTC GACGGCACTT ATCCGCCTGG TACTGAGCAA	1980
AACCCCGCTA ATCCTAATCC TTCTCTTGAG GAGTCTCAGC CTCTTAATAC TTTCATGTTT	2040
CAGAATAATA GGTTCGAAA TAGGCAGGGG GCATTAAC TG TTTATACGGG CACTGTACT	2100
CAAGGCACTG ACCCCGTTAA AACTTATTAC CAGTACACTC CTGTATCATC AAAAGCCATG	2160
TATGACGCTT ACTGGAACGG TAAATTCAGA GACTGCGCTT TCCATTCTGG CTTTAATGAA	2220
GATCCATTCTG TTTGTGAATA TCAAGGCCAA TCGTCTGACC TGCCTCAACC TCCTGTCAAT	2280
GCTGGCGGCG GCTCTGGTGG TGGTTCTGGT GCGGCTCTG AGGGTGGTGG CTCTGAGGGT	2340
GGCGGTTCTG AGGGTGGCGG CTCTGAGGGA GCGGTTCCG GTGGTGGCTC TGGTTCCGGT	2400
GATTTTGATT ATGAAAAGAT GGCAAACGCT AATAAGGGG CTATGACCGA AAATGCCGAT	2460
GAAAACGCGC TACAGTCTGA CGCTAAAGGC AAACCTTGATT CTGTCGCTAC TGATTACGGT	2520
GCTGCTATCG ATGGTTTCAT TGGTGACGTT TCCGGCCTTG CTAATGGTAA TGGTGCTACT	2580
GGTGATTTTG CTGGCTCTAA TTCCCAAATG GCTCAAGTCG GTGACGGTGA TAATTCACCT	2640
TTAATGAATA ATTTCCGTCA ATATTTACCT TCCCTCCCTC AATCGGTTGA ATGTCGCCCT	2700
TTTGTCTTTA GCGCTGGTAA ACCATATGAA TTTTCTATTG ATTGTGACAA AATAAACTTA	2760

TTCCGTGGTG TCTTTGCGTT TCTTTTATAT GTTGCCACCT TTATGTATGT ATTTTCTACG	2820
TTTGCTAACA TACTGCGTAA TAAGGAGTCT TAATCATGCC AGTTCTTTTG GGTATTCCGT	2880
TATTATTGCG TTTCCTCGGT TTCCTTCTGG TAACTTTGTT CGGCTATCTG CTTACTTTTC	2940
TTAAAAAGGG CTTCGGTAAG ATAGCTATTG CTATTTTATT GTTTCTTGCT CTTATTATTG	3000
GGCTTAACTC AATTCTTGTT GGTTATCTCT CTGATATTAG CGCTCAATTA CCCTCTGACT	3060
TTGTTTCAAGG TGTTTCAAGT ATTCTCCCGT CTAATGCGCT TCCCTGTTTT TATGTTATTC	3120
TCTCTGTAAA GGCTGCTATT TTCATTTTTG ACGTTAAACA AAAAATCGTT TCTTATTTGG	3180
ATTGGGATAA ATAATATGGC TGTTTATTTT GTAAGTGGCA AATTAGGCTC TGGAAAGACG	3240
CTCGTTAGCG TTGGTAAGAT TCAGGATAAA ATTGTAGCTG GGTGCAAAAT AGCAACTAAT	3300
CTTGATTTAA GGCTTCAAAA CCTCCCGCAA GTCGGGAGGT TCGCTAAAAC GCCTCGCGTT	3360
CTTAGAATAC CGGATAAGCC TTCTATATCT GATTTGCTTG CTATTGGGCG CGGTAATGAT	3420
TCCTACGATG AAAATAAAAA CGGCTTGCTT GTTCTCGATG AGTGCGGTAC TTGGTTTAAAT	3480
ACCCGTTCTT GGAATGATAA GGAAAGACAG CCGATTATTG ATTGGTTTCT ACATGCTCGT	3540
AAATTAGGAT GGGATATTAT TTTTCTTGTT CAGGACTTAT CTATTGTTGA TAAACAGGCG	3600
CGTTCTGCAT TAGCTGAACA TGTTGTTTAT TGTCGTCGTC TGGACAGAAT TACTTTACCT	3660
TTTGTCGGTA CTTTATATTC TCTTATTACT GGCTCGAAAA TGCCTCTGCC TAAATTACAT	3720
GTTGGCGTTG TTAAATATGG CGATTCTCAA TTAAGCCCTA CTGTTGAGCG TTGGCTTTAT	3780
ACTGGTAAGA ATTTGTATAA CGCATATGAT ACTAAACAGG CTTTTTCTAG TAATTATGAT	3840
TCCGGTGTTT ATTCTTATTT AACGCCTTAT TTATCACACG GTCGGTATTT CAAACCATTA	3900
AATTTAGGTC AGAAGATGAA GCTTACTAAA ATATATTTGA AAAAGTTTTT ACGCGTTCTT	3960
TGTCTTGCGA TTGGATTTGC ATCAGCATTT ACATATAGTT ATATAACCCA ACCTAAGCCG	4020
GAGGTAAAAA AGGTAGTCTC TCAGACCTAT GATTTTGATA AATTCATAT TGAATCTTCT	4080
CAGCGTCTTA ATCTAAGCTA TCGCTATGTT TTCAAGGATT CTAAGGGAAA ATTAATTAAT	4140
AGCGACGATT TACAGAAGCA AGGTATTCCA CTCACATATA TTGATTTATG TACTGTTTCC	4200
ATTAAAAAAG GTAATTCAAA TGAAATTGTT AAATGTAATT AATTTTGTTT TCTTGATGTT	4260
TGTTTCATCA TCTTCTTTTG CTCAGGTAAT TGAAATGAAT AATTCGCCTC TCGCGGATTT	4320
TGTAAGTTGG TATTCAAAGC AATCAGGCGA ATCCGTTATT GTTTCTCCCG ATGTAAAAGG	4380
TACTGTTACT GTATATTCAT CTGACGTTAA ACCTGAAAAT CTACGCAATT TCTTTATTTT	4440
TGTTTTACGT GCTAATAATT TTGATATGGT TGGTTCAATT CCTTCCATAA TTCAGAAGTA	4500
TAATCCAAAC AATCAGGATT ATATTGATGA ATTGCCATCA TCTGATAATC AGGAATATGA	4560

TGATAATTCC GCTCCTTCTG GTGGTTTCTT TGTTCCGCAA AATGATAATG TTA	4620
TTTAAAAATT AATAACGTTC GGGCAAAGGA TTTAATACGA GTTGTCGAAT TGTTTGTAAA	4680
GTCTAATACT TCTAAATCCT CAAATGTATT ATCTATTGAC GGCTCTAATC TATTAGTTGT	4740
TAGTGACCT AAAGATATTT TAGATAACCT TCCTCAATTC CTTTCTACTG TTGATTTGCC	4800
AACTGACCAG ATATTGATTG AGGGTTTGAT ATTTGAGGTT CAGCAAGGTG ATGCTTTAGA	4860
TTTTTCATTT GCTGCTGGCT CTCAGCGTGG CACTGTTGCA GCGGTGTTA ATACTGACCG	4920
CCTCACCTCT GTTTTATCTT CTGCTGGTGG TTCGTTCCGT ATTTTAAATG GCGATGTTTT	4980
AGGGCTATCA GTTCGCGCAT TAAAGACTAA TAGCCATTCA AAAATATTGT CTGTGCCACG	5040
TATTCTTACG CTTTCAGGTC AGAAGGGTTC TATCTCTGTT GGCCAGAATG TCCCTTTTAT	5100
TACTGGTCGT GTGACTGGTG AATCTGCCAA TGTAATAAAT CCATTCAGA CGATTGAGCG	5160
TCAAAATGTA GGTATTTCCA TGAGCGTTTT TCCTGTTGCA ATGGCTGGCG GTAATATTGT	5220
TCTGGATATT ACCAGCAAGG CCGATAGTTT GAGTTCTTCT ACTCAGGCAA GTGATGTTAT	5280
TACTAATCAA AGAAGTATTG CTACAACGGT TAATTTGCGT GATGGACAGA CTCTTTTACT	5340
CGGTGGCCTC ACTGATTATA AAAACACTTC TCAAGATTCT GCGGTACCGT TCCTGTCTAA	5400
AATCCCTTTA ATCGGCCTCC TGTTTAGCTC CCGCTCTGAT TCCAACGAGG AAAGCACGTT	5460
ATACGTGCTC GTCAAAGCAA CCATAGTACG CGCCCTGTAG CGGCGCATTG AGCGCGGCGG	5520
GTGTGGTGGT TACGCGCAGC GTGACCGCTA CACTTGCCAG CGCCCTAGCG CCCGCTCCTT	5580
TCGCTTTCTT CCCTTCCTTT CTCGCCACGT TCGCCGGCTT TCCCCGTCAA GCTCTAAATC	5640
GGGGGCTCCC TTTAGGGTTC CGATTTAGTG CTTTACGGCA CCTCGACCCC AAAAACTTG	5700
ATTTGGGTGA TGGTTCACGT AGTGGGCCAT CGCCCTGATA GACGGTTTTT CGCCCTTTGA	5760
CGTTGGAGTC CACGTTCTTT AATAGTGGAC TCTTGTTCCA AACTGGAACA AACTCAACC	5820
CTATCTCGGG CTATTCTTTT GATTTATAAG GGATTTTGCC GATTTTCGAA CCACCATCAA	5880
ACAGGATTTT CGCCTGCTGG GGCAAACCAG CGTGGACCGC TTGCTGCAAC TCTCTAGGG	5940
CCAGGCGGTG AAGGGCAATC AGCTGTTGCC CGTCTCGCTG GTGAAAAGAA AAACCACCCT	6000
GGCGCCCAAT ACGCAAACCG CCTCTCCCCG CGCGTTGGCC GATTCATTAA TGCAGCTGGC	6060
ACGACAGGTT TCCCGACTGG AAAGCGGGCA GTGAGCGCAA CGCAATTAAT GTGAGTTAGC	6120
TCACTCATTG GGCACCCAG GCTTTACACT TTATGCTTCC GGCTCGTATG TTGTGTGGAA	6180
TTGTGAGCGG ATAACAATTT CACACGCGTC ACTTGGCACT GGCCGTCGTT TTACAACGTC	6240
GTGACTGGGA AAACCCTGGC GTTACCCAAG CTTTGTACAT GGAGAAAATA AAGTGAAACA	6300
AAGCACTATT GCACTGGCAC TCTTACCGTT ACCGTTACTG TTTACCCCTG TGACAAAAGC	6360

CGCCAGGTC CAGCTGCTCG AGTCAGGCCT ATTGTGCCCA GGGGATTGTA CTAGTGGATC 6420
 CTAGGCTGAA GGCGATGACC CTGCTAAGGC TGCATTCAAT AGTTTACAGG CAAGTGCTAC 6480
 TGAGTACATT GGCTACGCTT GGGCTATGGT AGTAGTTATA GTTGGTGCTA CCATAGGGAT 6540
 TAAATTATTC AAAAAGTTTA CGAGCAAGGC TTCTTAAGCA ATAGCGAAGA GGCCCGCACC 6600
 GATCGCCCTT CCCAACAGTT GCGCAGCCTG AATGGCGAAT GGCGCTTTGC CTGGTTTCCG 6660
 GCACCAGAAG CGGTGCCGGA AAGCTGGCTG GAGTGCGATC TTCCTGAGGC CGATACGGTC 6720
 GTCGTCCCCT CAAACTGGCA GATGCACGGT TACGATGCGC CCATCTACAC CAACGTAACC 6780
 TATCCCATTA CGGTCAATCC GCCGTTTGTT CCCACGGAGA ATCCGACGGG TTGTTACTCG 6840
 CTCACATTTA ATGTTGATGA AAGCTGGCTA CAGGAAGGCC AGACGCGAAT TATTTTTGAT 6900
 GGCCTTCCTA TTGGTTAAAA AATGAGCTGA TTTAACAAAA ATTTAACGCG AATTTTAACA 6960
 AAATATTAAC GTTTACAATT TAAATATTTG CTTATACAAT CTTCTGTTT TTGGGGCTTT 7020
 TCTGATTATC AACCAGGGTA CATATGATTG ACATGCTAGT TTTACGATTA CCGTTCATCG 7080
 ATTCTCTTGT TTGCTCCAGA CTCTCAGGCA ATGACCTGAT AGCCTTTGTA GATCTCTCAA 7140
 AAATAGCTAC CCTCTCCGGC ATTAATTTAT CAGCTAGAAC GGTGAATAT CATATTGATG 7200
 GTGATTGAC TGTCTCCGGC CTTTCTCACC CTTTGAATC TTTACCTACA CATTACTCAG 7260
 GCATTGCATT TAAAATATAT GAGGGTTCTA AAAATTTTTA TCCTTGCGTT GAAATAAAGG 7320
 CTTCTCCCGC AAAAGTATTA CAGGGTCATA ATGTTTTTGG TACAACCGAT TTAGCTTTAT 7380
 GCTCTGAGGC TTTATTGCTT AATTTTGCTA ATTCTTTGCC TTGCCTGTAT GATTTATTGG 7440
 ACGTT 7445

(2) INFORMATION FOR SEQ ID NO:4:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 7409 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: both
- (D) TOPOLOGY: circular

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:4:

AATGCTACTA CTATTAGTAG AATTGATGCC ACCTTTTCAG CTCGCGCCCC AAATGAAAAT 60
 ATAGCTAAAC AGGTTATTGA CCATTTGCGA AATGTATCTA ATGGTCAAAC TAAATCTACT 120
 CGTTCGCAGA ATTGGGAATC AACTGTTACA TGGAATGAAA CTTCCAGACA CCGTACTTTA 180
 GTTGCATATT TAAAACATGT TGAGCTACAG CACCAGATTC AGCAATTAAG CTCTAAGCCA 240
 TCTGCAAAAA TGACCTCTTA TCAAAAGGAG CAATTAAAGG TACTCTCTAA TCCTGACCTG 300

TTGGAGTTTG	CTTCCGGTCT	GGTTCGCTTT	GAAGCTCGAA	TTAAAACGCG	ATATTTGAAG	360
TCTTTCGGGC	TTCCTCTTAA	TCTTTTTGAT	GCAATCCGCT	TTGCTTCTGA	CTATAATAGT	420
CAGGGTAAAG	ACCTGATTTT	TGATTTATGG	TCATTCTCGT	TTTCTGAACT	GTTTAAAGCA	480
TTTGAGGGGG	ATTCAATGAA	TATTTATGAC	GATTCCGCAG	TATTGGACGC	TATCCAGTCT	540
AAACATTTTA	CTATTACCCC	CTCTGGCAAA	ACTTCTTTTG	CAAAAGCCTC	TCGCTATTTT	600
GGTTTTTATC	GTCGTCTGGT	AAACGAGGGT	TATGATAGTG	TTGCTCTTAC	TATGCCTCGT	660
AATTCCTTTT	GGCGTTATGT	ATCTGCATTA	GTTGAATGTG	GTATTCCTAA	ATCTCAACTG	720
ATGAATCTTT	CTACCTGTAA	TAATGTTGTT	CCGTTAGTTC	GTTTTATTAA	CGTAGATTTT	780
TCTTCCCAAC	GTCCTGACTG	GTATAATGAG	CCAGTTCTTA	AAATCGCATA	AGGTAATTCA	840
CAATGATTAA	AGTTGAAATT	AAACCATCTC	AAGCCCAATT	TACTACTCGT	TCTGGTGTTT	900
CTCGTCAGGG	CAAGCCTTAT	TCACTGAATG	AGCAGCTTTG	TTACGTTGAT	TTGGGTAATG	960
AATATCCGGT	TCTTGTC AAG	ATTACTCTTG	ATGAAGGTCA	GCCAGCCTAT	GCGCCTGGTC	1020
TGTACACCGT	TCATCTGTCC	TCTTTC AAAG	TTGGTCAGTT	CGGTTCCCTT	ATGATTGACC	1080
GTCTGCGCCT	CGTTCCGGCT	AAGTAACATG	GAGCAGGTCG	CGGATTTCGA	CACAAATTTAT	1140
CAGGCGATGA	TACAAATCTC	CGTTGTACTT	TGTTTCGCGC	TTGGTATAAT	CGCTGGGGGT	1200
CAAAGATGAG	TGTTTTAGTG	TATTCTTTTG	CCTCTTTCGT	TTTAGGTTGG	TGCCTTCGTA	1260
GTGGCATTAC	GTATTTTACC	CGTTTAATGG	AAACTTCCTC	ATGAAAAAGT	CTTTAGTCCT	1320
CAAAGCCTCT	GTAGCCGTTG	CTACCCTCGT	TCCGATGCTG	TCTTTCGCTG	CTGAGGGTGA	1380
CGATCCCGCA	AAAGCGGCCT	TTAACTCCCT	GCAAGCCTCA	GCGACCGAAT	ATATCGGTTA	1440
TGCGTGGGCG	ATGGTTGTTG	TCATTGTCGG	CGCAACTATC	GGTATCAAGC	TGTTTAAGAA	1500
ATTCACCTCG	AAAGCAAGCT	GATAAACCGA	TACAATTAAA	GGCTCCTTTT	GGAGCCTTTT	1560
TTTTTGAGAG	TTTTCAACGT	GAAAAAATTA	TTATTGCGAA	TTCTTTTAGT	TGTTCCTTTC	1620
TATTCTCACT	CCGCTGAAAC	TGTTGAAAGT	TGTTTAGCAA	AACCCCATAC	AGAAAATTCA	1680
TTTACTAACG	TCTGGAAAGA	CGACAAAAC	TTAGATCGTT	ACGCTAACTA	TGAGGGTTGT	1740
CTGTGGAATG	CTACAGGCGT	TGTAGTTTGT	ACTGGTGACG	AAACTCAGTG	TTACGGTACA	1800
TGGGTTCCCTA	TTGGGCTTGC	TATCCCTGAA	AATGAGGGTG	GTGGCTCTGA	GGGTGGCGGT	1860
TCTGAGGGTG	GCGGTTCTGA	GGGTGGCGGT	ACTAAACCTC	CTGAGTACGG	TGATACACCT	1920
ATTCCGGGGCT	ATACTTATAT	CAACCCTCTC	GACGGCACTT	ATCCGCCTGG	TACTGAGCAA	1980
AACCCCGCTA	ATCCTAATCC	TTCTCTTGAG	GAGTCTCAGC	CTCTTAATAC	TTTCATGTTT	2040
CAGAATAATA	GGTTCCGAAA	TAGGCAGGGG	GCATTAACTG	TTTATACGGG	CACTGTTACT	2100

CAAGGCACTG	ACCCCGTTAA	AACTTATTAC	CAGTACACTC	CTGTATCATC	AAAAGCCATG	2160
TATGACGCTT	ACTGGAACGG	TAAATTCAGA	GACTGCGCTT	TCCATTCTGG	CTTTAATGAA	2220
GATCCATTCTG	TTTGTGAATA	TCAAGGCCAA	TCGTCTGACC	TGCCTCAACC	TCCTGTCAAT	2280
GCTGGCGGCG	GCTCTGGTGG	TGGTTCTGGT	GGCGGCTCTG	AGGGTGGTGG	CTCTGAGGGT	2340
GGCGGTTCTG	AGGGTGGCGG	CTCTGAGGGA	GGCGGTTCCG	GTGGTGGCTC	TGGTTCGGT	2400
GATTTTGATT	ATGAAAAGAT	GGCAAACGCT	AATAAGGGGG	CTATGACCGA	AAATGCCGAT	2460
GAAAACGCGC	TACAGTCTGA	CGCTAAAGGC	AAACTTGATT	CTGTCGCTAC	TGATTACGGT	2520
GCTGCTATCG	ATGGTTTCAT	TGGTGACGTT	TCCGGCCTTG	CTAATGGTAA	TGGTGCTACT	2580
GGTGATTTTG	CTGGCTCTAA	TTCCCAAATG	GCTCAAGTCG	GTGACGGTGA	TAATTCACCT	2640
TTAATGAATA	ATTTCCGTCA	ATATTTACCT	TCCCTCCCTC	AATCGGTTGA	ATGTCGCCCT	2700
TTTGTCTTTA	GCGCTGGTAA	ACCATATGAA	TTTTCTATTG	ATTGTGACAA	AATAAACTTA	2760
TTCCGTGGTG	TCTTTGCGTT	TCTTTTATAT	GTTGCCACCT	TTATGTATGT	ATTTTCTACG	2820
TTTGCTAACA	TACTGCGTAA	TAAGGAGTCT	TAATCATGCC	AGTTCTTTTG	GGTATTCCGT	2880
TATTATTGCG	TTTCCTCGGT	TTCTTCTGG	TAACTTTGTT	CGGCTATCTG	CTTACTTTTC	2940
TTAAAAAGGG	CTTCGGTAAG	ATAGCTATTG	CTATTTTCATT	GTTTCTTGCT	CTTATTATTG	3000
GGCTTAACTC	AATTCTTG TG	GGTTATCTCT	CTGATATTAG	CGCTCAATTA	CCCTCTGACT	3060
TTGTTCAAGG	TGTTCAAGTTA	ATTCTCCCGT	CTAATGCGCT	TCCCTGTTTT	TATGTTATTC	3120
TCTCTGTAAA	GGCTGCTATT	TTCATTTTTG	ACGTTAAACA	AAAAATCGTT	TCTTATTTGG	3180
ATTGGGATAA	ATAATATGGC	TGTTTTATTT	GTAAGTGGCA	AATTAGGCTC	TGGAAAGACG	3240
CTCGTTAGCG	TTGGTAAGAT	TCAGGATAAA	ATTGTAGCTG	GGTGCAAAAT	AGCAACTAAT	3300
CTTGATTTAA	GGCTTCAAAA	CCTCCCGCAA	GTCGGGAGGT	TCGCTAAAC	GCCTCGCGTT	3360
CTTAGAATAC	CGGATAAGCC	TTCTATATCT	GATTTGCTTG	CTATTGGGCG	CGGTAATGAT	3420
TCCTACGATG	AAAAATAAAA	CGGCTTGCTT	GTTCTCGATG	AGTGCGGTAC	TTGGTTTAAT	3480
ACCCGTTCTT	GGAATGATAA	GGAAAGACAG	CCGATTATTG	ATTGGTTTCT	ACATGCTCGT	3540
AAATTAGGAT	GGGATATTAT	TTTTCTTGTT	CAGGACTTAT	CTATTGTTGA	TAAACAGGCG	3600
CGTTCTGCAT	TAGCTGAACA	TGTTGTTTAT	TGTCGTCGTC	TGGACAGAAT	TACTTTACCT	3660
TTTGTGCGTA	CTTTATATTC	TCTTATTACT	GGCTCGAAAA	TGCCTCTGCC	TAAATTACAT	3720
GTTGGCGTTG	TTAAATATGG	CGATTCTCAA	TTAAGCCCTA	CTGTTGAGCG	TTGGCTTTAT	3780
ACTGGTAAGA	ATTTGTATAA	CGCATATGAT	ACTAAACAGG	CTTTTTCTAG	TAATTATGAT	3840
TCCGGTGTTT	ATTCTTATTT	AACGCCTTAT	TTATCACACG	GTCGGTATTT	CAAACCATTA	3900

AATTTAGGTC	AGAAGATGAA	GCTTACTAAA	ATATATTTGA	AAAAGTTTTC	ACGCGTTCCT	3960
TGTCTTGCGA	TTGGATTTGC	ATCAGCATTT	ACATATAGTT	ATATAACCCA	ACCTAAGCCG	4020
GAGGTTAAAA	AGGTAGTCTC	TCAGACCTAT	GATTTTGATA	AATTCACTAT	TGACTCTTCT	4080
CAGCGTCTTA	ATCTAAGCTA	TCGCTATGTT	TTCAAGGATT	CTAAGGGAAA	ATTAATTAAT	4140
AGCGACGATT	TACAGAAGCA	AGGTTATTCA	CTCACATATA	TTGATTTATG	TACTGTTTCC	4200
ATTAAAAAAG	GTAATTCAAA	TGAAATTGTT	AAATGTAATT	AATTTTGTTT	TCTTGATGTT	4260
TGTTTCATCA	TCTTCTTTTG	CTCAGGTAAT	TGAAATGAAT	AATTCGCCTC	TGCGCGATTT	4320
TGTAACCTGG	TATTCAAAGC	AATCAGGCGA	ATCCGTTATT	GTTTCTCCCG	ATGTAAAAGG	4380
TACTGTTACT	GTATATTCAT	CTGACGTAA	ACCTGAAAAT	CTACGCAATT	TCTTTATTTT	4440
TGTTTTACGT	GCTAATAATT	TTGATATGGT	TGGTTCAATT	CCTTCCATAA	TTCAGAAGTA	4500
TAATCCAAAC	AATCAGGATT	ATATTGATGA	ATTGCCATCA	TCTGATAATC	AGGAATATGA	4560
TGATAATTCC	GCTCCTTCTG	GTGGTTTCTT	TGTTCCGCAA	AATGATAATG	TACTCAAAC	4620
TTTTAAAATT	AATAACGTTT	GGGCAAAGGA	TTTAATACGA	GTTGTGGAAT	TGTTTGTAAG	4680
GTCTAATACT	TCTAAATCCT	CAAATGTATT	ATCTATTGAC	GGCTCTAATC	TATTAGTTGT	4740
TAGTGCACCT	AAAGATATTT	TAGATAACCT	TCCTCAATTC	CTTTCTACTG	TTGATTTGCC	4800
AACTGACCAG	ATATTGATTG	AGGGTTTGAT	ATTTGAGGTT	CAGCAAGGTG	ATGCTTTAGA	4860
TTTTTCATTT	GCTGCTGGCT	CTCAGCGTGG	CACTGTTGCA	GGCGGTGTTA	ATACTGACCG	4920
CCTCACCTCT	GTTTTATCTT	CTGCTGGTGG	TTCGTTGCGT	ATTTTTAATG	GCGATGTTTT	4980
AGGGCTATCA	GTTGCGCAT	TAAAGACTAA	TAGCCATTCA	AAAATATTGT	CTGTGCCACG	5040
TATTCTTACG	CTTTCAGGTC	AGAAGGGTTC	TATCTCTGTT	GGCCAGAATG	TCCCTTTTAT	5100
TACTGGTCGT	GTGACTGGTG	AATCTGCCAA	TGTAAATAAT	CCATTTCAGA	CGATTGAGCG	5160
TCAAAATGTA	GGTATTTCCA	TGAGCGTTTT	TCCTGTTGCA	ATGGCTGGCG	GTAATATTGT	5220
TCTGGATATT	ACCAGCAAGG	CCGATAGTTT	GAGTTCTTCT	ACTCAGGCAA	GTGATGTTAT	5280
TACTAATCAA	AGAAGTATTG	CTACAACGGT	TAATTTGCGT	GATGGACAGA	CTCTTTTACT	5340
CGGTGGCCTC	ACTGATTATA	AAAACACTTC	TCAAGATTCT	GGCGTACCGT	TCCTGTCTAA	5400
AATCCCTTTA	ATCGGCCTCC	TGTTTAGCTC	CCGCTCTGAT	TCCAACGAGG	AAAGCACGTT	5460
ATACGTGCTC	GTCAAAGCAA	CCATAGTACG	CGCCCTGTAG	CGGCGCATTA	AGCGCGGCGG	5520
GTGTGGTGGT	TACGCGCAGC	GTGACCGCTA	CACTTGCCAG	CGCCCTAGCG	CCCGCTCCTT	5580
TCGCTTTCTT	CCCTTCCTTT	CTCGCCACGT	TCGCCGGCTT	TCCCCGTCAA	GCTCTAAATC	5640
GGGGGCTCCC	TTTAGGGTTC	CGATTTAGTG	CTTTACGGCA	CCTCGACCCC	AAAAAACTTG	5700

ATTTGGGTGA TGGTTCACGT AGTGGGCCAT CGCCCTGATA GACGGTTTTT CGCCCTTTGA	5760
CGTTGGAGTC CACGTTCTTT AATAGTGGAC TCTTGTTCCA AACTGGAACA AACTCAACC	5820
CTATCTCGGG CTATTCTTTT GATTATAAG GGATTTTGCC GATTTCGGAA CCACCATCAA	5880
ACAGGATTTT CGCCTGCTGG GGCAAACCAG CGTGGACCGC TTGCTGCAAC TCTCTCAGGG	5940
CCAGGCGGTG AAGGGCAATC AGCTGTTGCC CGTCTCGCTG GTGAAAAGAA AAACCACCCT	6000
GGCGCCCAAT ACGCAAACCG CCTCTCCCGG CGCGTTGGCC GATTCATTAA TGCAGCTGGC	6060
ACGACAGGTT TCCCGACTGG AAAGCGGGCA GTGAGCGCAA CGCAATTAAT GTGAGTTAGC	6120
TCACTCATTG GGCACCCCAG GCTTTACACT TTATGCTTCC GGCTCGTATG TTGTGTGGAA	6180
TTGTGAGCGG ATAACAATTT CACACGCGTC ACTTGGCACT GGCCGTCGTT TTACAACGTC	6240
GTGACTGGGA AAACCCTGGC GTTACCCAAG CTTTGTACAT GGAGAAAATA AAGTGAAACA	6300
AAGCACTATT GCACTGGCAC TCTTACCGTT ACTGTTTACC CCTGTGGCAA AAGCCTATGG	6360
GGGGTTTATG ACTTCTGAGG GATCCGGAGC TGAAGGCGAT GACCCTGCTA AGGCTGCATT	6420
CAATAGTTTA CAGGCAAGTG CTAAGTGTGTA CATTTGGCTAC GCTTGGGCTA TGGTAGTAGT	6480
TATAGTTGGT GCTACCATAG GGATTAAATT ATTCAAAAAG TTTACGAGCA AGGCTTCTTA	6540
AGCAATAGCG AAGAGGCCCG CACCGATCGC CCTTCCCAAC AGTTGCGCAG CCTGAATGGC	6600
GAATGGCGCT TTGCCTGGTT TCCGGCACCA GAAGCGGTGC CGGAAAGCTG GCTGGAGTGC	6660
GATCTTCCTG AGGCCGATAC GGTCGTCGTC CCCTCAAACCT GGCAGATGCA CGGTTACGAT	6720
GCGCCCATCT ACACCAACGT AACCTATCCC ATTACGGTCA ATCCGCCGTT TGTTCACAG	6780
GAGAATCCGA CGGGTTGTTA CTCGCTCACA TTAAATGTTG ATGAAAGCTG GCTACAGGAA	6840
GGCCAGACGC GAATTATTTT TGATGGCGTT CCTATTGGTT AAAAAATGAG CTGATTTAAC	6900
AAAAATTTAA CGCGAATTTT AACAAAATAT TAACGTTTAC AATTTAAATA TTTGCTTATA	6960
CAATCTTCCT GTTTTTGGGG CTTTTCTGAT TATCAACCGG GGTACATATG ATTGACATGC	7020
TAGTTTACG ATTACCGTTC ATCGATTCTC TTGTTTGCTC CAGACTCTCA GGCAATGACC	7080
TGATAGCCTT TGATAGATCTC TCAAAAATAG CTACCCTCTC CGGCATTAAT TTATCAGCTA	7140
GAACGGTTGA ATATCATATT GATGGTGATT TGACTGTCTC CGGCCTTTCT CACCCTTTTG	7200
AATCTTTACC TACACATTAC TCAGGCATTG CATTTAAAAT ATATGAGGGT TCTAAAAATT	7260
TTTATCCTTG CGTTGAAATA AAGGCTTCTC CCGCAAAGT ATTACAGGGT CATAATGTTT	7320
TTGGTACAAC CGATTTAGCT TTATGCTCTG AGGCTTTATT GCTTAATTTT GCTAATTCTT	7380
TGCCTTGCCT GTATGATTTA TTGGACGTT	7409

(2) INFORMATION FOR SEQ ID NO:5:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 7294 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: both
- (D) TOPOLOGY: circular

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:5:

```

AATGCTACTA CTATTAGTAG AATTGATGCC ACCTTTTCAG CTCGCGCCCC AAATGAAAAT      60
ATAGCTAAAC AGGTTATTGA CCATTTGCGA AATGTATCTA ATGGTCAAAC TAAATCTACT      120
CGTTCGCAGA ATTGGGAATC AACTGTTACA TGGAATGAAA CTTCCAGACA CCGTACTTTA      180
GTTGCATATT TAAAACATGT TGAGCTACAG CACCAGATTC AGCAATTAAG CTCTAAGCCA      240
TCTGCAAAAA TGACCTCTTA TCAAAAGGAG CAATTAAAGG TACTCTCTAA TCCTGACCTG      300
TTGGAGTTTG CTTCCGGTCT GGTTCGCTTT GAAGCTCGAA TTAAAACGCG ATATTTGAAG      360
TCTTTCGGGC TTCCTCTTAA TCTTTTTGAT GCAATCCGCT TTGCTTCTGA CTATAATAGT      420
CAGGGTAAAG ACCTGATTTT TGATTTATGG TCATTCTCGT TTTCTGAACT GTTTAAAGCA      480
TTTGAGGGGG ATTCAATGAA TATTTATGAC GATTCCGCAG TATTGGACGC TATCCAGTCT      540
AAACATTTTA CTATTACCCC CTCTGGCAAA ACTTCTTTTG CAAAAGCCTC TCGCTATTTT      600
GGTTTTTATC GTCGTCTGGT AAACGAGGGT TATGATAGTG TTGCTCTTAC TATGCCTCGT      660
AATTCCTTTT GCGGTTATGT ATCTGCATTA GTTGAATGTG GTATTCCTAA ATCTCAACTG      720
ATGAATCTTT CTACCTGTAA TAATGTTGTT CCGTTAGTTC GTTTTATTAA CGTAGATTTT      780
TCTTCCCAAC GTCCTGACTG GTATAATGAG CCAGTTCTTA AAATCGCATA AGGTAATTCA      840
CAATGATTAA AGTTGAAATT AAACCATCTC AAGCCCAATT TACTACTCGT TCTGGTGTTT      900
CTCGTCAGGG CAAGCCTTAT TCACTGAATG AGCAGCTTTG TTACGTTGAT TTGGGTAATG      960
AATATCCGGT TCTTGTCAAG ATTACTCTTG ATGAAGGTCA GCCAGCCTAT GCGCCTGGTC     1020
TGACACCGT TCATCTGTCC TCTTCAAAG TTGGTCAGTT CGGTTCCCTT ATGATTGACC     1080
GTCTGCGCCT CGTTCCGGCT AAGTAACATG GAGCAGGTCG CGGATTTCGA CACAATTTAT     1140
CAGGCGATGA TACAAATCTC CGTTGTACTT TGTTTCGCGC TTGGTATAAT CGCTGGGGGT     1200
CAAAGATGAG TGTTTTAGTG TATTCTTTCG CCTCTTTCGT TTTAGGTTGG TGCCTTCGTA     1260
GTGGCATTAC GTATTTTACC CGTTTAATGG AACTTCCTC ATGAAAAAGT CTTTAGTCCT     1320
CAAAGCCTCT GTAGCCGTTG CTACCCTCGT TCCGATGCTG TCTTTCGCTG CTGAGGGTGA     1380
CGATCCCGCA AAAGCGGCCT TTAACCTCCT GCAAGCCTCA GCGACCGAAT ATATCGGTTA     1440

```

TGCGTGGGCG	ATGGTTGTTG	TCATTGTCGG	CGCAACTATC	GGTATCAAGC	TGTTTAAGAA	1500
ATTCACCTCG	AAAGCAAGCT	GATAAACCGA	TACAATTAAA	GGCTCCTTTT	GGAGCCTTTT	1560
TTTTTGGAGA	TTTTCAACGT	GAAAAAATTA	TTATTGCGAA	TTCCTTTAGT	TGTTCCTTTC	1620
TATTCTCACT	CCGCTGAAAC	TGTTGAAAGT	TGTTTAGCAA	AACCCCATAC	AGAAAATTCA	1680
TTTACTAACG	TCTGGAAAGA	CGACAAAAC	TTAGATCGTT	ACGCTAACTA	TGAGGGTTGT	1740
CTGTGGAATG	CTACAGGCGT	TGTAGTTTGT	ACTGGTGACG	AAACTCAGTG	TTACGGTACA	1800
TGGGTTCCCTA	TTGGGCTTGC	TATCCCTGAA	AATGAGGGTG	GTGGCTCTGA	GGGTGGCGGT	1860
TCTGAGGGTG	GCGGTTCTGA	GGGTGGCGGT	ACTAAACCTC	CTGAGTACGG	TGATACACCT	1920
ATTCCGGGCT	ATACTTATAT	CAACCCTCTC	GACGGCACTT	ATCCGCCTGG	TACTGAGCAA	1980
AACCCCGCTA	ATCCTAATCC	TTCTCTTGAG	GAGTCTCAGC	CTCTTAATAC	TTTCATGTTT	2040
CAGAATAATA	GGTTCCGAAA	TAGGCAGGGG	GCATTAAC	TTTATACGGG	CACTGTTACT	2100
CAAGGCACTG	ACCCCGTTAA	AACTTATTAC	CAGTACACTC	CTGTATCATC	AAAAGCCATG	2160
TATGACGCTT	ACTGGAACGG	TAAATTCAGA	GACTGCGCTT	TCCATTCTGG	CTTTAATGAA	2220
GATCCATTCTG	TTTGTGAATA	TCAAGGCCAA	TCGTCTGACC	TGCCTCAACC	TCCTGTCAAT	2280
GCTGGCGGCG	GCTCTGGTGG	TGGTCTGGT	GGCGGCTCTG	AGGGTGGTGG	CTCTGAGGGT	2340
GGCGGTTCTG	AGGGTGGCGG	CTCTGAGGGA	GGCGGTTCCG	GTGGTGGCTC	TGGTTCGGGT	2400
GATTTTGATT	ATGAAAAGAT	GGCAAACGCT	AATAAGGGGG	CTATGACCGA	AAATGCCGAT	2460
GAAAACGCGC	TACAGTCTGA	CGCTAAAGGC	AACTTGATT	CTGTCGCTAC	TGATTACGGT	2520
GCTGCTATCG	ATGGTTTCAT	TGGTGACGTT	TCCGGCCTTG	CTAATGGTAA	TGGTGCTACT	2580
GGTGATTTTG	CTGGCTCTAA	TTCCCAAATG	GCTCAAGTCG	GTGACGGTGA	TAATTCACCT	2640
TTAATGAATA	ATTTCCGTCA	ATATTTACCT	TCCCTCCCTC	AATCGGTTGA	ATGTCGCCCT	2700
TTTGTCTTTA	GCGCTGGTAA	ACCATATGAA	TTTTCTATTG	ATTGTGACAA	AATAAACTTA	2760
TTCCGTGGTG	TCTTTGCGTT	TCTTTTATAT	GTTGCCACCT	TTATGTATGT	ATTTTCTACG	2820
TTTGCTAACA	TACTGCGTAA	TAAGGAGTCT	TAATCATGCC	AGTTCTTTTG	GGTATTCCGT	2880
TATTATTGCG	TTTCCTCGGT	TTCCTTCTGG	TAACTTTGTT	CGGCTATCTG	CTTACTTTTC	2940
TTAAAAAGGG	CTTCGGTAAG	ATAGCTATTG	CTATTTCACT	GTTTCTTGCT	CTTATTATTG	3000
GGCTTAACTC	AATTCTTG	GGTTATCTCT	CTGATATTAG	CGCTCAATTA	CCCTCTGACT	3060
TTGTTCAGGG	TGTTCAAGTTA	ATTCTCCCGT	CTAATGCGCT	TCCCTGTTTT	TATGTTATTC	3120
TCTCTGTAAA	GGCTGCTATT	TTCATTTTTG	ACGTTAAACA	AAAAATCGTT	TCTTATTTGG	3180
ATTGGGATAA	ATAATATGGC	TGTTTATTTT	GTAAC	TGGAAAGACG		3240

CTCGTTAGCG	TTGGTAAGAT	TCAGGATAAA	ATTGTAGCTG	GGTGCAAAAT	AGCAACTAAT	3300
CTTGATTAA	GGCTTCAAAA	CCTCCCGCAA	GTCGGGAGGT	TCGCTAAAAC	GCCTCGCGTT	3360
CTTAGAATAC	CGGATAAGCC	TTCTATATCT	GATTTGCTTG	CTATTGGGCG	CGGTAATGAT	3420
TCCTACGATG	AAAAATAAAA	CGGCTTGCTT	GTTCTCGATG	AGTGCGGTAC	TTGGTTTAAAT	3480
ACCCGTTCTT	GGAATGATAA	GGAAAGACAG	CCGATTATTG	ATTGGTTTCT	ACATGCTCGT	3540
AAATTAGGAT	GGGATATTAT	CTTCCTTGTT	CAGGACTTAT	CTATTGTTGA	TAAACAGGCG	3600
CGTTCTGCAT	TAGCTGAACA	TGTTGTTTAT	TGTCGTCGTC	TGGACAGAAT	TACTTTACCT	3660
TTTGTCGGTA	CTTTATATTC	TCTTATTACT	GGCTCGAAAA	TGCCTCTGCC	TAAATTACAT	3720
GTTGGCGTTG	TTAAATATGG	CGATTCTCAA	TTAAGCCCTA	CTGTTGAGCG	TTGGCTTTAT	3780
ACTGGTAAGA	ATTTGTATAA	CGCATATGAT	ACTAAACAGG	CTTTTTCTAG	TAATTATGAT	3840
TCCGGTGTTT	ATTCTTATTT	AACGCCTTAT	TTATCACACG	GTCGGTATTT	CAAACCATTA	3900
AATTTAGGTC	AGAAGATGAA	GCTTACTAAA	ATATATTTGA	AAAAGTTTTC	ACGCGTTCTT	3960
TGTCTTGCGA	TTGGATTTGC	ATCAGCATTT	ACATATAGTT	ATATAACCCA	ACCTAAGCCG	4020
GAGGTTAAAA	AGGTAGTCTC	TCAGACCTAT	GATTTTGATA	AATTCACTAT	TGACTCTTCT	4080
CAGCGTCTTA	ATCTAAGCTA	TCGCTATGTT	TTCAAGGATT	CTAAGGGAAA	ATTAATTAAT	4140
AGCGACGATT	TACAGAAGCA	AGGTTATTCA	CTCACATATA	TTGATTTATG	TACTGTTTCC	4200
ATTAAAAAGG	TAATTCAAAT	GAAATTGTTA	AATGTAATTA	ATTTTGTTTT	CTTGATGTTT	4260
GTTTCATCAT	CTTCTTTTGC	TCAGGTAATT	GAAATGAATA	ATTTCGCCTCT	GCGCGATTTT	4320
GTAACCTGGT	ATTCAAAGCA	ATCAGGCGAA	TCCGTTATTG	TTTCTCCCGA	TGTAAAAGGT	4380
ACTGTTACTG	TATATTCATC	TGACGTTAAA	CCTGAAAATC	TACGCAATTT	CTTTATTTCT	4440
GTTTTACGTG	CTAATAATTT	TGATATGGTT	GGTTCAATTC	CTTCCATTAT	TTAGAAGTAT	4500
AATCCAAACA	ATCAGGATTA	TATTGATGAA	TTGCCATCAT	CTGATAATCA	GGAATATGAT	4560
GATAATTCCG	CTCCTTCTGG	TGGTTTCTTT	GTTCCGCAAA	ATGATAATGT	TACTCAAACCT	4620
TTTAAAATTA	ATAACGTTTCG	GGCAAAGGAT	TTAATACGAG	TTGTCGAATT	GTTTGTAAG	4680
TCTAATACTT	CTAAATCCTC	AAATGTATTA	TCTATTGACG	GCTCTAATCT	ATTAGTTGTT	4740
AGTGACACCTA	AAGATATTTT	AGATAACCTT	CCTCAATTCC	TTTCTACTGT	TGATTTGCCA	4800
ACTGACCAGA	TATTGATTGA	GGGTTTGATA	TTTGAGGTTT	AGCAAGGTGA	TGCTTTAGAT	4860
TTTTCATTTG	CTGCTGGCTC	TCAGCGTGCC	ACTGTTGCAG	GCGGTGTTAA	TACTGACCGC	4920
CTCACCTCTG	TTTTATCTTC	TGCTGGTGGT	TCGTTCCGTA	TTTTTAATGG	CGATGTTTTA	4980
GGGCTATCAG	TTGCGCATT	AAAGACTAAT	AGCCATTCAA	AAATATTGTC	TGTGCCACGT	5040

ATTCTTACGC TTTCAGGTCA GAAGGGTTCT ATCTCTGTTG GCCAGAATGT CCCTTTTATT	5100
ACTGGTCGTG TGA CTGGTGA ATCTGCCAAT GTAAATAATC CATTTCAGAC GATTGAGCGT	5160
CAAAATGTAG GTATTTCCAT GAGCGTTTTT CCTGTTGCAA TGGCTGGCGG TAATATTGTT	5220
CTGGATATTA CCAGCAAGGC CGATAGTTTG AGTTCTTCTA CTCAGGCAAG TGATGTTATT	5280
ACTAATCAAA GAAGTATTGC TACAACGGTT AATTTGCGTG ATGGACAGAC TCTTTTACTC	5340
GGTGGCCTCA CTGATTATAA AAACACTTCT CAAGATTCTG GCGTACCGTT CCTGTCTAAA	5400
ATCCCTTTAA TCGGCCTCCT GTTTAGCTCC CGCTCTGATT CCAACGAGGA AAGCACGTTA	5460
TACGTGCTCG TCAAAGCAAC CATAGTACGC GCCCTGTAGC GGCGCATTAA GCGCGGCGGG	5520
TGTGGTGGTT ACGCGCAGCG TGACCGCTAC ACTTGCCAGC GCCCTAGCGC CCGCTCCTTT	5580
CGCTTTCTTC CCTTCCTTTC TCGCCACGTT CGCCGGCTTT CCCCCTCAAG CTCTAAATCG	5640
GGGGCTCCCT TTAGGGTTCC GATTTAGTGC TTTACGGCAC CTCGACCCCA AAAA ACTTGA	5700
TTTGGGTGAT GGTTACGTA GTGGGCCATC GCCCTGATAG ACGGTTTTTC GCCCTTTGAC	5760
GTTGGAGTCC ACGTTCTTTA ATAGTGGACT CTTGTTCCAA ACTGGAACAA CACTCAACCC	5820
TATCTCGGGC TATTCTTTTG ATTTATAAGG GATTTTGCCG ATTTTCGGAAC CACCATCAAA	5880
CAGGATTTTC GCCTGCTGGG GCAAACCAGC GTGGACCGCT TGCTGCAACT CTCTCAGGGC	5940
CAGGCGGTGA AGGGCAATCA GCTGTTGCCC GTCTCGCTGG TGAAAAGAAA AACCACCCTG	6000
GCGCCCAATA CGCAAACCGC CTCTCCCCGC GCGTTGGCCG ATTCATTAAT GCAGCTGGCA	6060
CGACAGGTTT CCCGACTGGA AAGCGGGCAG TGAGCGCAAC GCAATTAATG TGAGTTAGCT	6120
CACTCATTAG GCACCCAGG CTTTACACTT TATGCTTCCG GCTCGTATGT TGTGTGGAAT	6180
TGTGAGCGGA TAACAATTTT ACACAGGAAA CAGCTATGAC CAGGATGTAC GAATTCGCAG	6240
GTAGGAGAGC TCGGCGGATC CGAGGCTGAA GGCGATGACC CTGCTAAGGC TGCATTCAAT	6300
AGTTTACAGG CAAGTGCTAC TGAGTACATT GGCTACGCTT GGGCTATGGT AGTAGTTATA	6360
GTTGGTGCTA CCATAGGGAT TAAATTATTC AAAAAGTTTA CGAGCAAGGC TTCTTAACCA	6420
GCTGGCGTAA TAGCGAAGAG GCCCGCACCG ATCGCCCTTC CCAACAGTTG CGCAGCCTGA	6480
ATGGCGAATG GCGCTTTGCC TGGTTTCCGG CACCAGAAGC GGTGCCGGAA AGCTGGCTGG	6540
AGTGCGATCT TCCTGAGGCC GATACGGTCG TCGTCCCCTC AACTGGCAG ATGCACGGTT	6600
ACGATGCGCC CATCTACACC AACGTAACCT ATCCCATTAC GGTCAATCCG CCGTTTGTTC	6660
CCACGGAGAA TCCGACGGGT TGTTACTCGC TCACATTTAA TGTTGATGAA AGCTGGCTAC	6720
AGGAAGGCCA GACGCGAATT ATTTTGTATG GCGTTCCTAT TGGTTAAAAA ATGAGCTGAT	6780
TTAACAAAAA TTTAACGCGA ATTTTAACAA AATATTAACG TTTACAATTT AAATATTTGC	6840

TTATACAATC TTCCTGTTTT TGGGGCTTTT CTGATTATCA ACCGGGGTAC ATATGATTGA	6900
CATGCTAGTT TTACGATTAC CGTTCATCGA TTCTCTTGTT TGCTCCAGAC TCTCAGGCAA	6960
TGACCTGATA GCCTTTGTAG ATCTCTCAAA AATAGCTACC CTCTCCGGCA TTAATTTATC	7020
AGCTAGAACG GTTGAATATC ATATTGATGG TGATTGACT GTCTCCGGCC TTTCTCACCC	7080
TTTTGAATCT TTACCTACAC ATTACTCAGG CATTGCATTT AAAATATATG AGGGTTCTAA	7140
AAATTTTTTAT CCTTGCGTTG AAATAAAGGC TTCTCCCGCA AAAGTATTAC AGGGTCATAA	7200
TGTTTTTGGT ACAACCGATT TAGCTTTATG CTCTGAGGCT TTATTGCTTA ATTTTGCTAA	7260
TTCTTTGCCT TGCCTGTATG ATTTATTGGA CGTT	7294

(2) INFORMATION FOR SEQ ID NO:6:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 7394 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: both
- (D) TOPOLOGY: circular

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:6:

AATGCTACTA CTATTAGTAG AATTGATGCC ACCTTTTCAG CTCGCGCCCC AAATGAAAAT	60
ATAGCTAAAC AGGTTATTGA CCATTTGCGA AATGTATCTA ATGGTCAAAC TAAATCTACT	120
CGTTGCGAGA ATTGGGAATC AACTGTTACA TGGAATGAAA CTTCCAGACA CCGTACTTTA	180
GTTGCATATT TAAAACATGT TGAGCTACAG CACCAGATTC AGCAATTAAG CTCTAAGCCA	240
TCTGCAAAAA TGACCTCTTA TCAAAAGGAG CAATTAAAGG TACTCTCTAA TCCTGACCTG	300
TTGGAGTTTG CTTCCGGTCT GGTTGCTTTT GAAGCTCGAA TTAAAACGCG ATATTTGAAG	360
TCTTTCGGGC TTCTCTTAA TCTTTTTGAT GCAATCCGCT TTGCTTCTGA CTATAATAGT	420
CAGGGTAAAG ACCTGATTTT TGATTTATGG TCATTCTCGT TTTCTGAACT GTTTAAAGCA	480
TTTGAGGGGG ATTCAATGAA TATTTATGAC GATTCCGCAG TATTGGACGC TATCCAGTCT	540
AAACATTTTA CTATTACCCC CTCTGGCAAA ACTTCTTTTG CAAAAGCCTC TCGCTATTTT	600
GGTTTTTATC GTCGTCTGGT AAACGAGGGT TATGATAGTG TTGCTCTTAC TATGCCTCGT	660
AATTCCTTTT GCGGTTATGT ATCTGCATTA GTTGAATGTG GTATTCCTAA ATCTCAACTG	720
ATGAATCTTT CTACCTGTAA TAATGTTGTT CCGTTAGTTC GTTTTATTAA CGTAGATTTT	780
TCTTCCCAAC GTCCTGACTG GTATAATGAG CCAGTTCTTA AAATCGCATA AGGTAATTCA	840
CAATGATTAA AGTTGAAATT AAACCATCTC AAGCCCAATT TACTACTCGT TCTGGTGTTT	900
CTCGTCAGGG CAAGCCTTAT TCACTGAATG AGCAGCTTTG TTACGTTGAT TTGGGTAATG	960

AATATCCGGT	TCTTGTCAG	ATTACTCTTG	ATGAAGGTCA	GCCAGCCTAT	GCGCCTGGTC	1020
TGTACACCGT	TCATCTGTCC	TCTTTCAAAG	TTGGTCAGTT	CGGTTCCCTT	ATGATTGACC	1080
GTCTGCGCCT	CGTTCGGGCT	AAGTAACATG	GAGCAGGTCG	CGGATTTCGA	CACAATTTAT	1140
CAGGCGATGA	TACAAATCTC	CGTTGTACTT	TGTTTCGCGC	TTGGTATAAT	CGCTGGGGGT	1200
CAAAGATGAG	TGTTTTAGTG	TATTCTTTCG	CCTCTTTCGT	TTTAGGTTGG	TGCCTTCGTA	1260
GTGGCATTAC	GTATTTTACC	CGTTTAATGG	AAACTTCCTC	ATGAAAAAGT	CTTTAGTCCT	1320
CAAAGCCTCT	GTAGCCGTTG	CTACCCCTCG	TCCGATGCTG	TCTTTCGCTG	CTGAGGGTGA	1380
CGATCCCGCA	AAAGCGGCCT	TTAACTCCCT	GCAAGCCTCA	GCGACCGAAT	ATATCGGTTA	1440
TGCGTGGGCG	ATGGTTGTTG	TCATTGTCGG	CGCAACTATC	GGTATCAAGC	TGTTTAAGAA	1500
ATTCACCTCG	AAAGCAAGCT	GATAAACCGA	TACAATTAAA	GGCTCCTTTT	GGAGCCTTTT	1560
TTTTTGGAGA	TTTTCAACGT	GAAAAAATTA	TTATTGCGAA	TTCCTTTAGT	TGTTCCTTTTC	1620
TATTCTCACT	CCGCTGAAAC	TGTTGAAAGT	TGTTTAGCAA	AACCCCATAC	AGAAAATTCA	1680
TTTACTAACG	TCTGGAAAGA	CGACAAAAC	TTAGATCGTT	ACGCTAACTA	TGAGGGTTGT	1740
CTGTGGAATG	CTACAGGCGT	TGTAGTTTGT	ACTGGTGACG	AAACTCAGTG	TTACGGTACA	1800
TGGGTTCCCTA	TTGGGCTTGC	TATCCCTGAA	AATGAGGGTG	GTGGCTCTGA	GGGTGGCGGT	1860
TCTGAGGGTG	GCGGTTCTGA	GGGTGGCGGT	ACTAAACCTC	CTGAGTACGG	TGATACACCT	1920
ATTCCGGGCT	ATACTTATAT	CAACCCTCTC	GACGGCACTT	ATCCGCCTGG	TACTGAGCAA	1980
AACCCCGCTA	ATCCTAATCC	TTCTCTTGAG	GAGTCTCAGC	CTCTTAATAC	TTTCATGTTT	2040
CAGAATAATA	GGTTCCGAAA	TAGGCAGGGG	GCATTAAC	TTTATACGGG	CACTGTTACT	2100
CAAGGCACTG	ACCCCGTTAA	AACTTATTAC	CAGTACACTC	CTGTATCATC	AAAAGCCATG	2160
TATGACGCTT	ACTGGAACGG	TAAATTCAGA	GACTGCGCTT	TCCATTCTGG	CTTTAATGAA	2220
GATCCATTCTG	TTTGTGAATA	TCAAGGCCAA	TCGTCTGACC	TGCCTCAACC	TCCTGTCAAT	2280
GCTGGCGGCG	GCTCTGGTGG	TGGTTCTGGT	GGCGGCTCTG	AGGGTGGTGG	CTCTGAGGGT	2340
GGCGGTTCTG	AGGGTGGCGG	CTCTGAGGGA	GGCGGTTCCG	GTGGTGGCTC	TGTTTCCGGT	2400
GATTTTGATT	ATGAAAAGAT	GGCAAACGCT	AATAAGGGGG	CTATGACCGA	AAATGCCGAT	2460
GAAAACGCGC	TACAGTCTGA	CGCTAAAGGC	AAACTTGATT	CTGTCGCTAC	TGATTACGGT	2520
GCTGCTATCG	ATGTTTTCAT	TGGTGACGTT	TCCGGCCTTG	CTAATGGTAA	TGGTGCTACT	2580
GGTGATTTTG	CTGGCTCTAA	TTCCCAAATG	GCTCAAGTCG	GTGACGGTGA	TAATTCACCT	2640
TTAATGAATA	ATTTCCGTCA	ATATTTACCT	TCCCTCCCTC	AATCGGTTGA	ATGTCGCCCT	2700
TTTGTCTTTA	GCGCTGGTAA	ACCATATGAA	TTTTCTATTG	ATTGTGACAA	AATAAACTTA	2760

TTCCGTGGTG	TCTTTGCGTT	TCTTTTATAT	GTTGCCACCT	TTATGTATGT	ATTTTCTACG	2820
TTTGCTAACA	TACTGCGTAA	TAAGGAGTCT	TAATCATGCC	AGTTCTTTTG	GGTATTCCGT	2880
TATTATTGCG	TTTCCTCGGT	TTCCTTCTGG	TAACCTTGTT	CGGCTATCTG	CTTACTTTTC	2940
TTAAAAAGGG	CTTCGGTAAG	ATAGCTATTG	CTATTTCAAT	GTTTCTTGCT	CTTATTATTG	3000
GGCTTAACTC	AATTCTTGTTG	GGTTATCTCT	CTGATATTAG	CGCTCAATTA	CCCTCTGACT	3060
TTGTTCAAGG	TGTTCAAGTTA	ATTCTCCCGT	CTAATGCGCT	TCCCTGTTTT	TATGTTATTC	3120
TCTCTGTAAA	GGCTGCTATT	TTCATTTTTG	ACGTAAACA	AAAAATCGTT	TCTTATTTGG	3180
ATTGGGATAA	ATAATATGGC	TGTTTATTTT	GTAAGTGGCA	AATTAGGCTC	TGGAAAGACG	3240
CTCGTTAGCG	TTGGTAAGAT	TTAGGATAAA	ATTGTAGCTG	GGTGCAAAAT	AGCAACTAAT	3300
CTTGATTTAA	GGCTTCAAAA	CCTCCCGCAA	GTCGGGAGGT	TCGCTAAAAC	GCCTCGCGTT	3360
CTTAGAATAC	CGGATAAGCC	TTCTATATCT	GATTTGCTTG	CTATTGGGCG	CGGTAATGAT	3420
TCCTACGATG	AAAATAAAAA	CGGCTTGCTT	GTTCTCGATG	AGTGCGGTAC	TTGGTTTAAT	3480
ACCCGTTCTT	GGAATGATAA	GGAAAGACAG	CCGATTATTG	ATTGGTTTCT	ACATGCTCGT	3540
AAATTAGGAT	GGGATATTAT	TTTTCTTGTT	CAGGACTTAT	CTATTGTTGA	TAAACAGGCG	3600
CGTTCTGCAT	TAGCTGAACA	TGTTGTTTAT	TGTCGTCGTC	TGGACAGAAT	TACTTTACCT	3660
TTTGTCGGTA	CTTTATATTC	TCTTATTACT	GGCTCGAAAA	TGCCTCTGCC	TAAATTACAT	3720
GTTGGCGTTG	TTAAATATGG	CGATTCTCAA	TTAAGCCCTA	CTGTTGAGCG	TTGGCTTTAT	3780
ACTGGTAAGA	ATTTGTATAA	CGCATATGAT	ACTAAACAGG	CTTTTTCTAG	TAATTATGAT	3840
TCCGGTGTTT	ATTCTTATTT	AACGCCTTAT	TTATCACACG	GTCGGTATTT	CAAACCATTA	3900
AATTTAGGTC	AGAAGATGAA	GCTTACTAAA	ATATATTTGA	AAAAGTTTTT	ACGCGTTCTT	3960
TGTCTTGCGA	TTGGATTTGC	ATCAGCATTT	ACATATAGTT	ATATAACCCA	ACCTAAGCCG	4020
GAGGTTAAAA	AGGTAGTCTC	TCAGACCTAT	GATTTTGATA	AATTCATAT	TGACTCTTCT	4080
CAGCGTCTTA	ATCTAAGCTA	TCGCTATGTT	TTCAAGGATT	CTAAGGGAAA	ATTAATTAAT	4140
AGCGACGATT	TACAGAAGCA	AGGTTATTCA	CTCACATATA	TTGATTTATG	TACTGTTTCC	4200
ATTAAAAAAG	GTAATTCAAA	TGAAATTGTT	AAATGTAATT	AATTTTGTTT	TCTTGATGTT	4260
TGTTTCATCA	TCTTCTTTTG	CTCAGGTAAT	TGAAATGAAT	AATTCGCCTC	TGCGCGATTT	4320
TGTAAGTTGG	TATTCAAAGC	AATCAGGCGA	ATCCGTTATT	GTTTCTCCCG	ATGTAAAAGG	4380
TACTGTTACT	GTATATTCAT	CTGACGTTAA	ACCTGAAAAT	CTACGCAATT	TCTTTATTTT	4440
TGTTTTACGT	GCTAATAATT	TTGATATGGT	TGGTTCAATT	CCTTCCATAA	TTCAGAAGTA	4500
TAATCCAAAC	AATCAGGATT	ATATTGATGA	ATTGCCATCA	TCTGATAATC	AGGAATATGA	4560

TGATAATTCC GCTCCTTCTG GTGGTTTCTT TGTTCCGCAA AATGATAATG TTA CTCAAAC	4620
TTTTAAAATT AATAACGTTT GGGCAAAGGA TTTAATACGA GTTGTCGAAT TGTTTGTA AA	4680
GTCTAATACT TCTAAATCCT CAAATGTATT ATCTATTGAC GGCTCTAATC TATTAGTTGT	4740
TAGTGACCT AAAGATATTT TAGATAACCT TCCTCAATTC CTTTCTACTG TTGATTTGCC	4800
AACTGACCAG ATATTGATTG AGGGTTTGAT ATTTGAGGTT CAGCAAGGTG ATGCTTTAGA	4860
TTTTTCATTT GCTGCTGGCT CTCAGCGTGG CACTGTTGCA GGC GGTGTTA ATACTGACCG	4920
CCTCACCTCT GTTTTATCTT CTGCTGGTGG TTCGTTCCGT ATTTTAAATG GCGATGTTTT	4980
AGGGCTATCA GTTCGCGCAT TAAAGACTAA TAGCCATTCA AAAATATTGT CTGTGCCACG	5040
TATTCTTACG CTTTCAGGTC AGAAGGGTTC TATCTCTGTT GGCCAGAATG TCCCTTTTAT	5100
TACTGGTCGT GTGACTGGTG AATCTGCCAA TGTAATAAT CCATTT CAGA CGATTGAGCG	5160
TCAAATGTA GGTATTTCCA TGAGCGTTTT TCCTGTTGCA ATGGCTGGCG GTAATATTGT	5220
TCTGGATATT ACCAGCAAGG CCGATAGTTT GAGTTCTTCT ACTCAGGCAA GTGATGTTAT	5280
TACTAATCAA AGAAGTATTG CTACAACGGT TAATTTGCGT GATGGACAGA CTCTTTTACT	5340
CGGTGGCCTC ACTGATTATA AAAACACTTC TCAAGATTCT GGCGTACCGT TCCTGTCTAA	5400
AATCCCTTTA ATCGGCCTCC TGTTTAGCTC CCGCTCTGAT TCCAACGAGG AAAGCACGTT	5460
ATACGTGCTC GTCAAAGCAA CCATAGTACG CGCCCTGTAG CGGCGCATTA AGCGCGGCGG	5520
GTGTGGTGGT TACGCGCAGC GTGACCGCTA CACTTGCCAG CGCCCTAGCG CCCGCTCCTT	5580
TCGCTTTCTT CCCTTCCTTT CTCGCCACGT TCGCCGGCTT TCCCCGTCAA GCTCTAAATC	5640
GGGGGCTCCC TTTAGGGTTC CGATTTAGTG CTTTACGGCA CCTCGACCCC AAAAACTTG	5700
ATTTGGGTGA TGGTTCACGT AGTGGGCCAT CGCCCTGATA GACGGTTTTT CGCCCTTTGA	5760
CGTTGGAGTC CACGTTCTTT AATAGTGGAC TCTTGTTCCA AACTGGAACA AACTCAACC	5820
CTATCTCGGG CTATTCTTTT GATTTATAAG GGATTTTGCC GATTTTCGGAA CCACCATCAA	5880
ACAGGATTTT CGCCTGCTGG GGCAAACCAG CGTGGACCGC TTGCTGCAAC TCTCTCAGGG	5940
CCAGGCGGTG AAGGGCAATC AGCTGTTGCC CGTCTCGCTG GTGAAAAGAA AAACCACCCT	6000
GGCGCCCAAT ACGCAAACCG CCTCTCCCCG CGCGTTGGCC GATTCATTAA TGCAGCTGGC	6060
ACGACAGGTT TCCCGACTGG AAAGCGGGCA GTGAGCGCAA CGCAATTAAT GTGAGTTAGC	6120
TCACTCATTG GGCACCCAG GCTTTACACT TTATGCTTCC GGCTCGTATG TTGTGTGGAA	6180
TTGTGAGCGG ATAACAATTT CACACGCGTC ACTTGGCACT GGCCGTCGTT TTACAACGTC	6240
GTGACTGGGA AAACCCTGGC GTTACCCAAG CTTTGTACAT GGAGAAAATA AAGTGAAACA	6300
AAGCACTATT GCACTGGCAC TCTTACCGTT ACTGTTTACC CCTGTGGCAA AAGCCCTTCT	6360

GAGGCATCCG GGAGCTGAAG GCGATGACCC TGCTAAGGCT GCATTCAATA GTTTACAGGC 6420
 AAGTGCTACT GAGTACATTG GCTACGCTTG GGCTATGGTA GTAGTTATAG TTGGTGCTAC 6480
 CATAGGGATT AAATTATTCA AAAAGTTTAC GAGCAAGGCT TCTTAAGCAA TAGCGAAGAG 6540
 GCCCGCACCG ATCGCCCTTC CCAACAGTTG CGCAGCCTGA ATGGCGAATG GCGCTTTGCC 6600
 TGGTTTCCGG CACCAGAAGC GGTGCCGGA AGCTGGCTGG AGTGCGATCT TCCTGAGGCC 6660
 GATACGGTCG TCGTCCCCTC AAAGTGGCAG ATGCACGGTT ACGATGCGCC CATCTACACC 6720
 AACGTAACCT ATCCCATTAC GGTCAATCCG CCGTTTGTTT CCACGGAGAA TCCGACGGGT 6780
 TGTTACTCGC TCACATTTAA TGTTGATGAA AGCTGGCTAC AGGAAGGCCA GACGCGAATT 6840
 ATTTTGTATG GCGTTCCTAT TGGTTAAAAA ATGAGCTGAT TTAACAAAAA TTTAACGCGA 6900
 ATTTTAACAA AATATTAACG TTTACAATTT AAATATTTGC TTATACAATC TTCCTGTTTT 6960
 TGGGGCTTTT CTGATTATCA ACCGGGGTAC ATATGATTGA CATGCTAGTT TTACGATTAC 7020
 CGTTCATCGA TTCTCTTGTT TGCTCCAGAC TCTCAGGCAA TGACCTGATA GCCTTTGTAG 7080
 ATCTCTCAAA AATAGCTACC CTCTCCGGCA TTAATTTATC AGCTAGAACG GTTGAATATC 7140
 ATATTGATGG TGATTTGACT GTCTCCGGCC TTTCTCACCC TTTTGAATCT TTACCTACAC 7200
 ATTACTCAGG CATTGCATTT AAAATATATG AGGGTTCTAA AAATTTTAT CTTGCGTTG 7260
 AAATAAAGGC TTCTCCCGCA AAAGTATTAC AGGGTCATAA TGTTTTTGGT ACAACCGATT 7320
 TAGCTTTATG CTCTGAGGCT TTATTGCTTA ATTTTGCTAA TTCTTTGCCT TGCCTGTATG 7380
 ATTTATTGGA CGTT 7394

(2) INFORMATION FOR SEQ ID NO:7:

- (i) SEQUENCE CHARACTERISTICS:
- (A) LENGTH: 37 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:7:

GATCCTAGGC TGAAGGCGAT GACCCTGCTA AGGCTGC

37

(2) INFORMATION FOR SEQ ID NO:8:

- (i) SEQUENCE CHARACTERISTICS:
- (A) LENGTH: 35 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:8:

ATTCAATAGT TTACAGGCAA GTGCTACTGA GTACA

35

(2) INFORMATION FOR SEQ ID NO:9:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 35 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:9:

TTGGCTACGC TTGGGCTATG GTAGTAGTTA TAGTT

35

(2) INFORMATION FOR SEQ ID NO:10:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 35 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:10:

GGTGCTACCA TAGGGATTAA ATTATTCAAA AAGTT

35

(2) INFORMATION FOR SEQ ID NO:11:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 18 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:11:

TACGAGCAAG GCTTCTTA

18

(2) INFORMATION FOR SEQ ID NO:12:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 39 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:12:

AGCTTAAGAA GCCTTGCTCG TAAACTTTT GAATAATTT

39

(2) INFORMATION FOR SEQ ID NO:13:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 36 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:13:

AATCCCTATG GTAGCACCAA CTATAACTAC TACCAT

36

(2) INFORMATION FOR SEQ ID NO:14:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 35 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:14:

AGCCCAAGCG TAGCCAATGT ACTCAGTAGC ACTTG

35

(2) INFORMATION FOR SEQ ID NO:15:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 34 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:15:

CCTGTAAACT ATTGAATGCA GCCTTAGCAG GGTC

34

(2) INFORMATION FOR SEQ ID NO:16:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 16 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:16:

ATCGCCTTCA GCCTAG

16

(2) INFORMATION FOR SEQ ID NO:17:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 27 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:17:

CTCGAATTCG TACATCCTGG TCATAGC

27

(2) INFORMATION FOR SEQ ID NO:18:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 21 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:18:

CATTTTTGCA GATGGCTTAG A

21

(2) INFORMATION FOR SEQ ID NO:19:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 18 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:19:

TAGCATTAAC GTCCAATA

18

(2) INFORMATION FOR SEQ ID NO:20:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 26 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:20:

ATATATTTTA GTAAGCTTCA TCTTCT

26

(2) INFORMATION FOR SEQ ID NO:21:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 23 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:21:

GACAAAGAAC GCGTGAAAAC TTT

23

(2) INFORMATION FOR SEQ ID NO:22:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 35 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:22:

GCGGGCCTCT TCGCTATTGC TTAAGAAGCC TTGCT

35

(2) INFORMATION FOR SEQ ID NO:23:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 48 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:23:

TTCAGCCTAG GATCCGCCGA GCTCTCCTAC CTGCGAATTC GTACATCC

48

(2) INFORMATION FOR SEQ ID NO:24:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 24 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:24:

TGGATTATAC TTCTAAATAA TGGA

24

(2) INFORMATION FOR SEQ ID NO:25:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 36 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:25:

TAACACTCAT TCCGGATGGA ATTCTGGAGT CTGGGT

36

(2) INFORMATION FOR SEQ ID NO:26:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 22 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:26:

AATTCGCCAA GGAGACAGTC AT

22

(2) INFORMATION FOR SEQ ID NO:27:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 39 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:27:

AATGAAATAC CTATTGCCTA CGGCAGCCGC TGGATTGTT

39

(2) INFORMATION FOR SEQ ID NO:28:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 39 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:28:

ATTACTCGCT GCCCAACCAG CCATGGCCGA GCTCGTGAT

39

(2) INFORMATION FOR SEQ ID NO:29:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 39 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:29:

GACCCAGACT CCAGATATCC AACAGGAATG AGTGTTAAT

39

(2) INFORMATION FOR SEQ ID NO:30:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 13 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:30:

TCTAGAACGC GTC

13

(2) INFORMATION FOR SEQ ID NO:31:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 35 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:31:

ACGTGACGCG TTCTAGAATT AACACTCATT CCTGT

35

(2) INFORMATION FOR SEQ ID NO:32:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 39 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:32:

TGGATATCTG GAGTCTGGGT CATCACGAGC TCGGCCATG

39

(2) INFORMATION FOR SEQ ID NO:33:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 39 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:33:

GCTGGTTGGG CAGCGAGTAA TAACAATCCA GCGGCTGCC

39

(2) INFORMATION FOR SEQ ID NO:34:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 37 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:34:

GTAGGCAATA GGTATTTTCAT TATGACTGTC CTTGGCG

37

(2) INFORMATION FOR SEQ ID NO:35:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 30 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:35:

TGACTGTCTC CTTGGCGTGT GAAATTGTTA

30

(2) INFORMATION FOR SEQ ID NO:36:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 36 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:36:

TAACACTCAT TCCGGATGGA ATTCTGGAGT CTGGGT

36

(2) INFORMATION FOR SEQ ID NO:37:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 25 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:37:

CAATTTTATC CTAAATCTTA CCAAC

25

(2) INFORMATION FOR SEQ ID NO:38:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 21 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:38:

CATTTTGTGCA GATGGCTTAG A

21

(2) INFORMATION FOR SEQ ID NO:39:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 21 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:39:

CGAAAGGGGG GTGTGCTGCA A

21

(2) INFORMATION FOR SEQ ID NO:40:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 18 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:40:

TAGCATTAAC GTCCAATA

18

(2) INFORMATION FOR SEQ ID NO:41:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 43 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:41:

AAACGACGGC CAGTGCCAAG TGACGCGTGT GAAATTGTTA TCC

43

(2) INFORMATION FOR SEQ ID NO:42:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 43 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:42:

GGCGAAAGGG AATTCTGCAA GGCGATTAAG CTTGGGTAAC GCC

43

(2) INFORMATION FOR SEQ ID NO:43:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 36 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:43:

GGCGTTACCC AAGCTTTGTA CATGGAGAAA ATAAAG

36

(2) INFORMATION FOR SEQ ID NO:44:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 42 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:44:

TGAAACAAAG CACTATTGCA CTGGCACTCT TACCGTTACC GT 42

(2) INFORMATION FOR SEQ ID NO:45:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 42 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:45:

TACTGTTTAC CCCTGTGACA AAAGCCGCCC AGGTCCAGCT GC 42

(2) INFORMATION FOR SEQ ID NO:46:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 44 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:46:

TCGAGTCAGG CCTATTGTGC CCAGGGATTG TACTAGTGA TCCG 44

(2) INFORMATION FOR SEQ ID NO:47:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 38 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:47:

TGGCGAAAGG GAATTCGGAT CCACTAGTAC AATCCCTG 38

(2) INFORMATION FOR SEQ ID NO:48:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 42 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:48:

GGCACAATAG GCCTGACTCG AGCAGCTGGA CCAGGGCGGC TT 42

(2) INFORMATION FOR SEQ ID NO:49:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 42 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:49:

TTGTCACAGG GGTAACAGT AACGGTAACG GTAAGTGTGC CA 42

(2) INFORMATION FOR SEQ ID NO:50:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 42 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:50:

GTGCAATAGT GCTTTGTTTC ACTTTATTTT CTCCATGTAC AA 42

(2) INFORMATION FOR SEQ ID NO:51:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 21 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:51:

TAACGGTAAG AGTGCCAGTG C 21

(52) INFORMATION FOR SEQ ID NO:52:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 68 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

- (ix) FEATURE:
 - (A) NAME/KEY: misc_difference
 - (B) LOCATION: replace(25, "")
 - (D) OTHER INFORMATION: /note= "M REPRESENTS AN EQUAL MIXTURE OF A AND C AT THIS LOCATION AND AT LOCATIONS 28, 31, 34, 37, 40, 43, 46 & 49"

- (xi) SEQUENCE DESCRIPTION: SEQ ID NO:52:

AGCTCCCGGA TGCCTCAGAA GATGMNNMNN MNNMNNMNNM NNMNNMNNMN NGGCTTTTGC 60

CACAGGGG 68

- (2) INFORMATION FOR SEQ ID NO:53:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 54 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

- (ix) FEATURE:
 - (A) NAME/KEY: misc_difference
 - (B) LOCATION: replace(17, "")
 - (D) OTHER INFORMATION: /note= "M REPRESENTS AN EQUAL MIXTURE OF A AND C AT THIS LOCATION AND AT LOCATIONS 20, 23, 26, 29, 32, 35, 38, 41, 44 & 50"

- (xi) SEQUENCE DESCRIPTION: SEQ ID NO:53:

CAGCCTCGGA TCCGCCMNNM NNMNNMNNMN NMNNMNNMNN MNNMNNATGM GAAT 54

- (2) INFORMATION FOR SEQ ID NO:54:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 27 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

- (xi) SEQUENCE DESCRIPTION: SEQ ID NO:54:

GGTAAACAGT AACGGTAAGA GTGCCAG 27

- (2) INFORMATION FOR SEQ ID NO:55:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 19 base pairs

- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:55:

GGGCTTTTGC CACAGGGGT

19

(2) INFORMATION FOR SEQ ID NO:56:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 63 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:56:

AGGGTCATCG CCTTCAGCTC CGGATCCCTC AGAAGTCATA AACCCCCCAT AGGCTTTTGC

60

CAC

63

(2) INFORMATION FOR SEQ ID NO:57:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 47 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:57:

TCGCCTTCAG CTCCCGGATG CCTCAGAAGC ATGAACCCCC CATAGGC

47

(2) INFORMATION FOR SEQ ID NO:58:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 25 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:58:

CAATTTTATC CTAAATCTTA CCAAC

25

(2) INFORMATION FOR SEQ ID NO:59:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 21 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single

(D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:59:

GCCTTCAGCC TCGGATCCGC C

21

(2) INFORMATION FOR SEQ ID NO:60:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 21 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:60:

CGGATGCCTC AGAAGCCCCN N

21

(2) INFORMATION FOR SEQ ID NO:61:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 30 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: single
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:61:

CGGATGCCTC AGAAGGGCTT TTGCCACAGG

30

114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000